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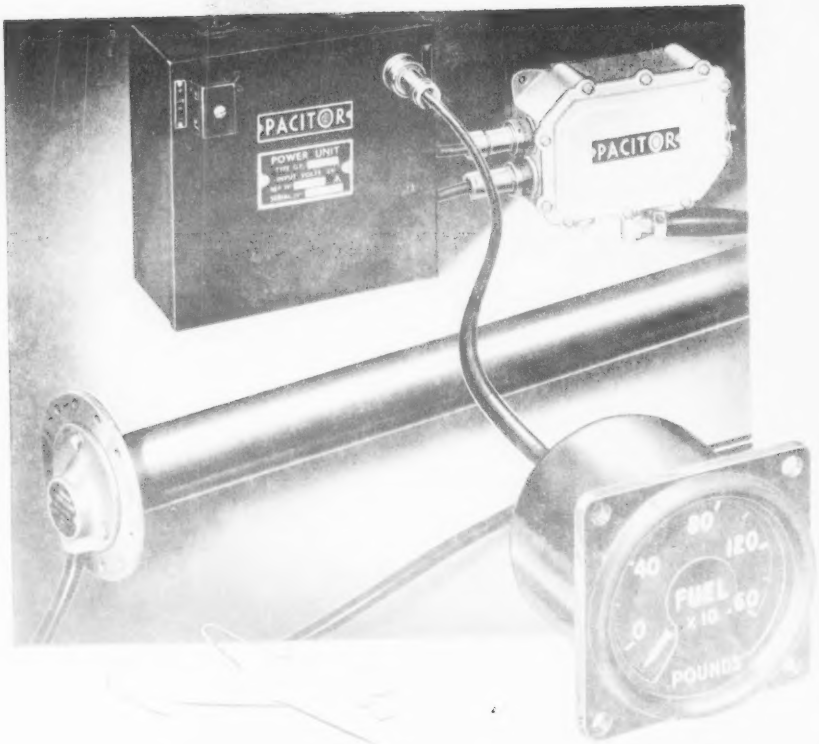
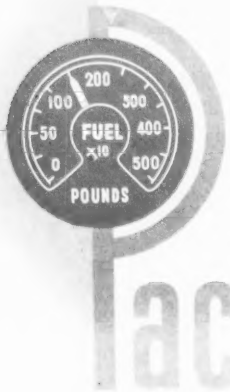
The Journal of

THE ROYAL AERONAUTICAL SOCIETY

DECEMBER 1947 NO 444 · VOL 51





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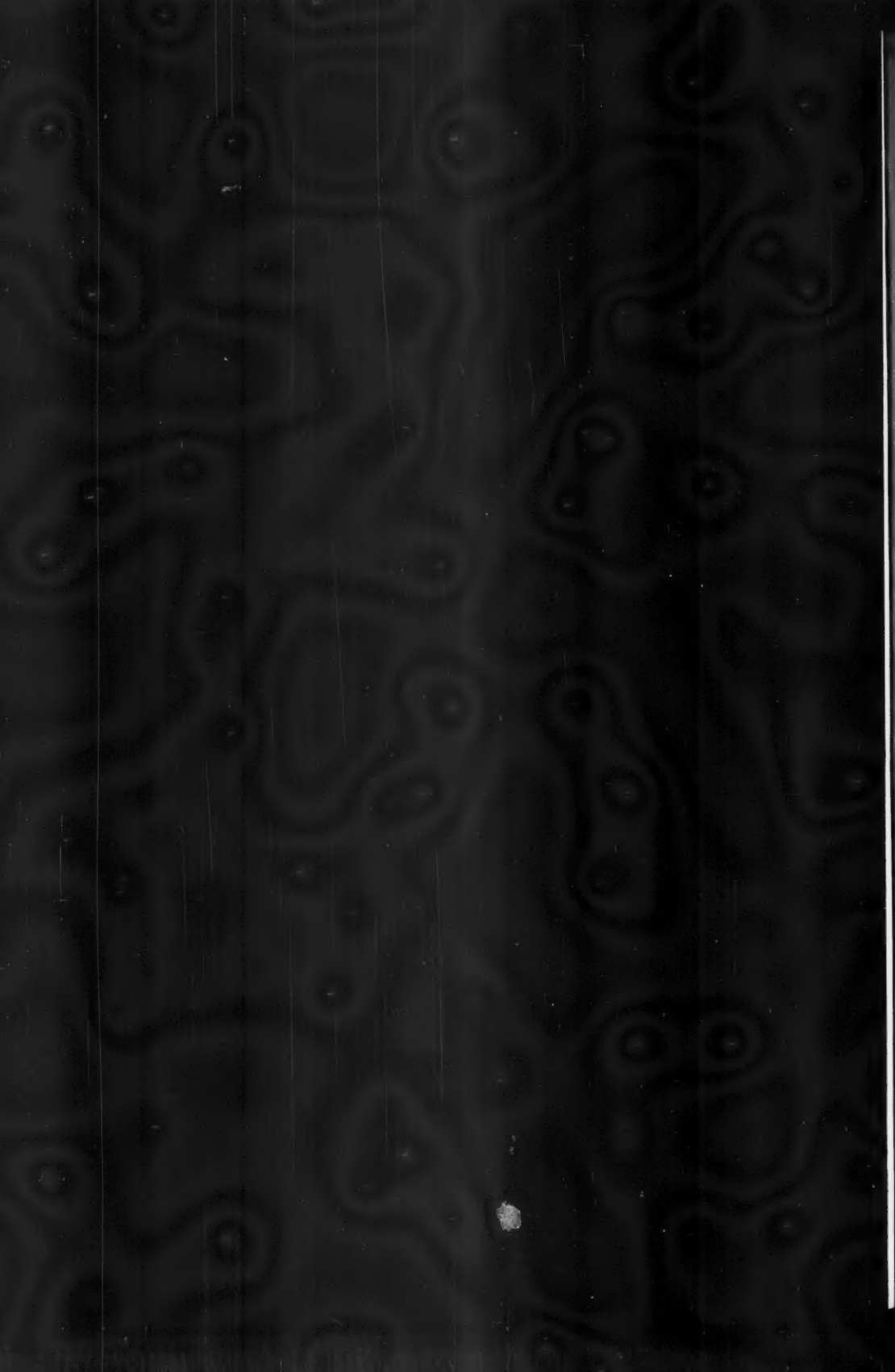

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THE ROYAL AERONAUTICAL SOCIETY
4 HAMILTON PLACE, PICCADILLY, LONDON, W.1

DECEMBER NOTICES 1947

JOURNAL PREMIUM AWARDS

The Council have set aside an annual sum of £250 for the award of premiums for papers published in the *Journal* and the Council hope that members (or non-members) will contribute papers on their own special subjects.

H.R.H. THE PRINCESS ELIZABETH, DUCHESS OF EDINBURGH

A message of loyal greetings was sent to H.M. the King, Patron of the Society, by the President on behalf of all members of the Society, on the occasion of the marriage of H.R.H. the Princess Elizabeth to H.R.H. the Duke of Edinburgh.

CONTENTS OF DECEMBER JOURNAL

Pressurisation and Cabin Air Control, by W. M. Widgery, F.R.Ae.S.
Maintenance Difficulties in the Field, by M. J. Kemper, M.B.E., A.R.Ae.S.
Index for 1947.

RECEPTION, 17th JANUARY AND 24th JANUARY 1948

A number of members of the Society have expressed a wish for a social function this Session and the Council have considered the suggestion in the light of the austerity conditions now ruling. The Council have also had under consideration the need to find an opportunity for members to see the Society's collection of aeronautical prints and rare books to which has been added recently, through the generosity of Sir Frederick Handley Page, the remarkable Hodgson-Cuthbert Collection, which was first formed in 1820.

The Council have come to the conclusion that these two matters can be combined.

On 17th January and 24th January 1948 Receptions will be held at No. 4 Hamilton Place by the President, Dr. H. Roxbee Cox, and Mrs. Roxbee Cox, supported by the Council. At these Receptions many of the most interesting parts of the Hodgson-Cuthbert Collection will be on view and tea will be provided for members and their friends.

The Receptions will begin at 3 p.m. and end at approximately 6.30 p.m. Tickets for tea will be 4/- each and each member may bring not more than three guests. Members should already have received an application form for tickets and it will be appreciated if they will make a special point of saying which date would be the most convenient.

CHRISTMAS HOLIDAYS

The Offices and Library of the Society will be closed from Wednesday evening, 24th December until Monday morning, 29th December 1947.

THE SOCIETY AND ITS MEMBERS

The following abstract from an address by Mr. Frank G. Woollard, M.B.E., as first Chairman of The Automobile Division of the Institution of Mechanical Engineers, is reprinted by kind permission:

What an Institution Does for Members

An institution confers professional status on its members—status which is becoming of increasing importance. This status provides what a University degree alone cannot do. By examination and by careful scutiny of the career of applicants for membership, it furnishes an assurance to those concerned, of practice in the science, art, and craft for which the institution is responsible.

Further, the tendency of governmental and official circles to recognise only those who carry the hall-mark of professional standing makes membership of an institution a necessity to all practising engineers. The professional status conferred upon a member of an institution is by no means to be despised.

One of the greater advantages of membership is the right to attend both formal and informal meetings in the metropolis, or at the local centres, and to join in the discussions. An even greater privilege lies in the opportunity for contributing papers and thus of enjoying a broad platform for the ventilation of new theories and for testing the opinion of fellow members. The educational value of writing a paper cannot be overestimated. This is a case where, without doubt, it is more blessed to give than to receive, hence I scarcely need mention the tangible awards in the shape of medals, prizes, and scholarships, which are a recognition of work of outstanding merit.

The social activities added to the technical meetings are a great aid in introducing members to each other. From such introductions there have been some very happy issues. The material advantages need no stressing; they are, of course, quite obvious. But the intangible benefits of acquaintance ripening into amity and the founding, among those having mutual interests, of friendships—even life-long friendships—are priceless legacies arising from the social functions of the institution.

What the Members Can Do for Their Institution

The fundamental law, that work done is a function of input less the losses absorbed in transforming energy into a more immediately useful form, is applicable to institutions as well as to machines.

This being so, members cannot expect to get more out of an institution than they put into it except, maybe, at the expense of other members. It follows that if a member or a prospective member says: " I cannot see what the institution can do for me," it is obvious that he has arrived at the stage when he should ask: " What am I doing or what can I do for the institution?"

The average member of an institution—that is to say, one who does no committee work—may perhaps wonder how he can contribute to the common cause. At first sight this, for, shall we say, a " private " member, may appear to be limited to paying his subscription, reading his journal, and making an occasional visit to his centre. But this would be taking a poor view of the opportunities that are available. May I then indicate how a " private " member can serve his institution.

Above all, members must uphold the dignity and the prestige of the institution by maintaining a code of conduct such as would be expected of professional men in other walks of life—the doctor, the lawyer, the accountant, and so on. This does not apply only to those engaged in consulting practice, but also to those who hold positions of responsibility in works and factories, to those who are in the operating or service fields, and to those who have the honour to serve in H.M. Forces.

The mere upholding of prestige and dignity may be regarded as a negative virtue, but it can be positive if every member endeavours to make his colleagues—and particularly the directorate under which he serves—" institution-conscious."

Members can also encourage the enlistment of new recruits, particularly of those who can be enrolled as graduates. Healthy societies are built upon their young and energetic members, and after a long and costly war, with its period of stasis in our affairs we need the younger men as active participants in our renaissance.

It goes without saying that members can only render effective assistance to the institution when they are in touch with institution matters. This contact is best achieved by attendance at centre meetings. This is, of course, not so much a professional duty as a privilege. The interchange of views in debate on the paper, or in discussion over coffee is of mutual value, for not only does it extend knowledge and promote good feeling, but it has the advantage of bringing out the " coming man."

WILBUR WRIGHT LECTURE

Mr. A. Gouge, B.Sc., F.R.Ae.S., will give the 36th Wilbur Wright Memorial Lecture on 27th May 1948. The subject will be announced later.

COMMONWEALTH FUND FELLOWSHIPS

Applications for the Commonwealth Fund Fellowships for 1948 must be received by the Secretary of the Committee of Award not later than the 1st February 1948.

The Fellowships, which are awarded by the Commonwealth Fund of New York and are tenable in the United States (involving an absence of 12 months), are open to persons who come within one or other of the following categories:

(1) For Ordinary Fellowships—Candidates of British descent who are domiciled in the United Kingdom of Great Britain and Northern Ireland, and are degree graduates of recognised universities therein. Candidates must be more than twenty-three years of age but must not have attained the age of thirty-five on 1st September of the year of award. These Fellowships are also open to candidates of British descent who have studied, but not necessarily graduated, at a university in the United Kingdom of Great Britain and Northern Ireland, and are degree graduates of a recognised university in Australia, New Zealand and South Africa, and who fulfil the conditions regarding age. Not more than twenty of these Fellowships will be offered in 1948.

(2) For Service Fellowships—Candidates of British descent who hold appointments overseas under the British Government, the Government of Australia, New Zealand and South Africa and the Governments of the British Colonies, Protectorates and Mandated Territories. Not more than five Service Fellowships will be offered in 1948.

(3) For Home Civil Service Fellowships—Candidates holding appointments in the Home Civil Service. Not more than three of these Fellowships will be offered in 1948.

Fellowships are not open to women.

Only those candidates will be considered who are prepared to give an undertaking that they will not accept another appointment until the expiration of the Fellowship, and that they will then return to Great Britain or to some other part of the British Empire and reside there for a period of not less than two years, unless they are permitted to remain in the United States for reasons acceptable to the Fund. No one is eligible for a Fellowship if he

has already studied or worked in any educational or research institution in the United States for one or more academic years.

The emolument attaching to each Fellowship, which is estimated at a minimum of approximately $3,500 for twelve months, is calculated to cover the full expenses of residence, study and travel in the United States during the year.

Generally, no limitation is imposed on the subject of study to be undertaken by the Fellow during the tenure of the Fellowship.

Full particulars and application forms may be obtained from the Secretary, Richard H. Simpson, Esq., 35 Portman Square, London, W.1.

THE FLIGHT TESTING OF HELICOPTERS by W. Stewart, B.Sc. — *Summary of Lecture to be given on 29th January* 1948.

Within the past few years, the helicopter has been developed to a stage when it can now be considered as an operational and commercial aircraft. Treating the helicopter as such, this lecture discusses the experience gained—mainly on the Sikorsky R-4B—in recent flight investigations of the aerodynamic characteristics of the helicopter, with particular emphasis on the development of suitable flight testing techniques.

In an investigation of the flow conditions through the rotor, the flight tests have established the induced velocity distribution in the hovering state and shown the applicability of propeller strip theory to the full-scale rotor. The flow pattern was obtained from visualisation of the streamlines by smoke filaments. This technique was also used to determine the flow patterns under various other operating conditions of the rotor and was particularly useful in an investigation of the vortex ring state, where a theoretical approach is not possible.

The performance work includes tests using a flight path recorder to improve the accuracy of the measurements. A comparison with the estimated performance is made. The effect of the ground cushion is also considered.

The stability and control investigations cover a series of general handling tests, static and dynamic stability measurements and include the effects of centre of gravity position, power-on and auto-rotation conditions. Blind flying on helicopters is also discussed.

LECTURE PROGRAMME—1947-1948

The Lectures will be held at 6 p.m. in the Lecture Hall of the Institution of Civil Engineers, Great George Street, S.W.1 (by permission of the Council of the Institution) unless otherwise stated. Tea will be served at 5.30 p.m.

Visitors are welcome, but should obtain tickets through a member of the Society.

Thursday, 18th December 1947—The Work of the High-Speed Tunnel, by Professor A. Thom, M.A., D.Sc., and W. G. A. Perring, F.R.Ae.S.

Thursday, 15th January 1948—Joint lecture with the Institute of Fuel. Gas Turbine Accessory Systems, by O. N. Lawrence, M.A., A.M.I.Mech.E., A.F.R.Ae.S.

Thursday, 29th January 1948—The Flight Testing of Helicopters, by W. Stewart, B.Sc.

Thursday, 12th February 1948—The Aerodynamics of the Gas Turbine, by A. R. Howell.

Thursday, 26th February 1948—The Evolution of the Design of an Aeroplane, by Professor R. L. Lickley, B.Sc., D.I.C., F.R.Ae.S.

Thursday, 18th March 1948—Flight Testing at High Subsonic Speeds, by H. Davies, B.A., M.Sc., A.F.R.Ae.S.

Saturday, 3rd April 1948—FULL DAY DISCUSSION ON SAFETY IN CIVIL AVIATION. Introductory Statements only will be made. Each will be followed by open discussion.

Morning Session

11 a.m.—Air Vice-Marshal D. C. T. Bennett, C.B., D.S.O., F.R.Ae.S., on The Economics of Safety.

12 noon—Professor A. A. Hall, M.Sc., M.A., F.R.Ae.S., on The Problems of Air Traffic Control.

1-2.30 p.m.—Luncheon Interval. Members and visitors should make their own arrangements for lunch.

Afternoon Session

2.30 p.m.—Dr. K. G. Bergin, M.A., M.D., M.B., B.Chir., M.R.C.S., L.R.C.P., A.F.R.Ae.S., on Physiological Aspects of Safety.

3.30 p.m.—General Discussion.

4.30-5 p.m.—Tea interval (tea provided).

Evening Session

5-.630 p.m.—General Discussion and summing-up.

Thursday, 15th April 1948—The Aerodynamic Problems of High Altitude Design, by W. E. W. Petter, B.A., F.R.Ae.S.

Thursday, 27th May 1948—The 36th Wilbur Wright Memorial Lecture will be read by A. Gouge, B.Sc., F.R.Ae.S.

BELFAST BRANCH

Tuesday, 9th December 1947—Title not yet agreed, Sir John Buchanan, C.B.E., F.R.Ae.S., A.M.I.Mech.E.

Tuesday, 6th January 1948—Some Experiences in Experimental Gliding, Professor Hill, M.C., M.Sc., M.I.Mech.E., F.R.Ae.S.

Friday, 23rd January 1948—Smoking concert.

Tuesday, 3rd February 1948—High Speed Flight, Dr. Hilton.

Tuesday, 24th February 1948—Evening of lecturettes.

Tuesday, 16th March 1948—Inside Occupied Japan, Mr. William Courtenay, M.M., A.R.Ae.S.

All meetings are held at the Assembly Hall, Belfast College of Technology, at **7.30** p.m.

BRISTOL BRANCH

Wednesday, 10th December 1947—Air Crew Training, by Captain A. C. P. Johnstone, O.B.E., A.F.R.Ae.S., F.R.Met.S., A/Manager, Airways Training Ltd. (Subject to his being available at this date. Members will be informed by post.)

Tuesday, 20th January 1948—Debate.

Wednesday, 11th February 1948—The Design of a Large Naval Vessel, by H. S. Pengelley, R.C.N.C., M.Inst.N.A., Assistant Director of Naval Construction, Admiralty.

Monday, 23rd February 1948—Accidents and Their Investigation, by Air Commodore Vernon Brown, C.B., O.B.E., M.A., F.R.Ae.S., Accidents Investigation Branch, Ministry of Civil Aviation.

Wednesday, 3rd March 1948—Reading of Prize-winning Papers by Junior Members.

Monday, 22nd March 1948—Operation of Civil Transport Aircraft, by N. E. Rowe, C.B.E., F.R.Ae.S., Controller of Research and Long Term Development, British European Airways.

Wednesday, 14th April 1948—Film Night and Annual General Meeting.

All meetings will be held in the Conference Room, Bristol Aeroplane Co. Ltd., Filton House, at 6.0 p.m.

GLOUCESTER AND CHELTENHAM BRANCH

Wednesday, 10th December 1947—Rotor Systems and Control Problems in the Helicopter, Raoul Hafner, Chief Designer, Helicopter Department, Bristol Aeroplane Co. — at Cheltenham.

Thursday, 15th January 1948—Film on Rocket Flight (Sound track in English)—at Gloucester.

Wednesday, 4th February 1948—Air Operations in the Battle of Britain, An Officer in the Royal Air Force—at Cheltenham.

Thursday, 4th March 1948—The Development of the A.S. Type Gas Turbine Engine, W. H. Lindsey, M.A., A.F.R.Ae.S.—at Gloucester.

Wednesday, 7th April 1948—Annual General Meeting followed by Film—at Cheltenham.

Gloucester meetings are held in the Wheatstone Hall, City Library, Brunswick Road, Gloucester, at 7.30 p.m. on *Thursdays*.

Cheltenham meetings are held in the Chemistry Lecture Theatre, Grammar School, Cheltenham, at 7.30 p.m. on *Wednesdays*.

LUTON BRANCH

Wednesday, 7th January 1948—Discussion Evening. Three papers will be read by members of the Branch and will be followed by discussions. Subjects: Aero-engines, Aircraft, Flying and Gliding.

Wednesday, 4th February 1948—Some Problems in Civil Aviation, by N. E. Rowe, C.B.E., B.Sc., D.I.C., F.R.Ae.S.

Both meetings will be held at the George Hotel, Luton, at 7 p.m.

MANCHESTER BRANCH

Wednesday, 17th December 1947—History of " Stooge " Radio Controlled Projectile, by Geoffrey Hall.

Thursday, 29th January 1948—Pressurisation, by G. Beardshall.

Thursday, 26th February 1948—Naval Aircraft, by Captain Fancourt.

Thursday, 1st April 1948—Flight Refuelling, by C. H. Latimer-Needham.

Meetings will be held at the Reynolds Hall, College of Technology, at 7.30 p.m.

PORTSMOUTH BRANCH

Friday, 2nd January 1948—Wind Tunnels, Open and Closed Types, by D. W. Bottle, of the R.A.E., Farnborough.

At the Cosham Civic Centre at 7 p.m.

PRESTON BRANCH

Wednesday, 10th December 1947—Fighter Design, by Professor R. L. Lickley, B.Sc., D.I.C., F.R.Ae.S. (Professor of Aircraft Design at the College of Aeronautics, Cranfield).

Wednesday, 7th January 1948—Problems of High Speed Flight, by D. L. Ellis, B.Sc., A.R.T.C., F.R.Ae.S. (Chief of Aerodynamics of the English Electric Company's Aircraft Division).

Wednesday, 28th January 1948—Photographic Interpretation of the Bomber Offensive against Germany, by S/Ldr. G. A. Morris, O.B.E. (formerly head of the Photographic Interpretation Section, H.Q., Bomber Command).

All lectures will be held, unless otherwise stated, at 7 p.m. in the Board Room of the Preston Chamber of Commerce, Fishergate, Preston (next to the Theatre Royal).

READING BRANCH

Friday, 12th December 1947—Annual General Meeting. Members are asked to make special efforts to attend. The meeting will be held in the Monthly Staff Dining Room, Miles Aircraft, Woodley Aerodrome, Reading, at 6.30 p.m.

SOUTHAMPTON BRANCH

Wednesday, 7th January 1948—Rotating Wing Aircraft, by C. G. Pullin.

Wednesday, 4th February 1948—Structures Testing by P. B. Walker, M.A., Ph.D., F.R.Ae.S.

Lectures will be held at University College, Southampton, at 7 p.m.

GRADUATES' AND STUDENTS' SECTION

Friday, 12th December 1947—Aircraft Design from the Airline Point of View, by Christopher Dykes, Deputy Chief Project Engineer, B.O.A.C.

Tuesday, 20th January 1948—Show of films on the helicopter, loaned by the Bell Helicopter Co. Commentary by Captain Cyril Turner, A.F.C., of Irvin-Bell Helicopter Sales Ltd.

Tuesday, 10th February 1948—Stability and Control Problems, by D. J. Lyons, Aero-Flight Section, R.A.E.

Wednesday, 25th February 1948—Suction Aerofoils, by B. Thwaites, Dept. of Aeronautics, Imperial College of Science and Technology.

Wednesday, 14th April 1948—The Influence of the Recent Civil Airworthiness Requirements on Civil Aircraft Design, by W. Tye, B.Sc., F.R.Ae.S., Air Registration Board.

Tuesday, 11th May 1948—The Light Aeroplane and the Future of Private Flying, by P. G. Masefield, M.A., F.R.Ae.S., Director General of Long Term Planning and Projects, Ministry of Civil Aviation.

All meetings will be held in the Library of the Royal Aeronautical Society, 4 Hamilton Place, W.1, at 7.30 p.m.

CHANGES OF ADDRESS

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).
Grade of membership.
New address (in block letters).
Old address.

Changes of address must be received *before the 15th of the month* in order to be effective for the Journal for the following month.

ELECTION OF MEMBERS

The following new members have been elected:—

Associate Fellows

Edward John Nicholas Archbold (from Graduate), Herman Pane Baker, Paul William Baker (from Associate), Dennis Frederick Barnes, George Thomas Winton Bees (from Graduate), Frederick James Bigg, Dennis Herbert Bonfield (from Graduate), J. Domaszewski, William Downes (from Graduate), Ernest Duckett, Reginald George Edkins, Geoffrey Dent Evans, Sydney Barrington Gates, William Hampton (from Graduate), Leslie Arthur Hopkins (from Graduate), Henry Norman Jones, William Prichard Jones, Janusz Kukucki, Alexander Lightbody, Harold Lurie (from Graduate), Roderick Alfred Manuel, Basil Marlow, Edgar Martin, Sydney Oldfield (from Associate), George Orloff, Frank Leslie Pape, John Walter Piggott (from Associate), John George Romeril, Robert Roy, Anthony Derick Ruscoe (from Graduate), Norman Sharp, Geoffrey Herbert Thomas (from Associate), Graham Wilson Topping (ex-Student), George Stanley Charles Trounce, Leonard Charles Williams.

Associates

William Charles Bartlett, Gerald Spencer Blackman (from Student), Maurice Leslie Howard Carter, William Chard, Peter Anthony Drillien, Frank Drinkwater, John Laurance Dugdale, Roderick Frank Harman, Adrianus Henderikus Davidus Hopener (from Student), Douglas David Jones (from Student), Frank Leslie Pearson, Ivor Henry Prickett, Frederick George Toone, Richard William Usher.

Graduates

Thomas Martin Chalmers, William Gascoygne Clennett, Peter Laurence Felton, Peter Thomas Fink, George Wallace Holt, Donald Brooksby Jacob, Thomas George Kent (from Student), Kenneth William Kimber, William Spencer Knowles, Eric Ernest Labram (from Student), John Magson (from Student), Maurice William Martin, Jack Allen Packett, Frank Packwood, Herbert Alfred Spufford, Norman Wyatt Taylor, Bernard Thomas Bertram Tomlinson, George Albert Turner (from Student), Spencer Marcus Willmott.

Students

Rex Leonard Bowman, Peter Bradshaw, James Rattray Cownie, Stanley Harold Dance, Clifford Henry Davis, Terence Edmund Ford, Ian Alexander Butler Gaunt, William Joseph Gornall, Jean Michael Hahn, Peter John Harvey, Cyril Gwynne Hughes, Leslie Walter Lawrence, Ernest Deryck Reginald Levey, Philip James Martin, Hugh Christopher Henry Merewether, Malcolm Hammond Niblett, Ernest Frederick Walter Phelps, Keith William Stanley Richards, Geoffrey Thomes Smailes, Philip Rayvatha Wijewardene, Winstone Harold Williamson.

Companions

John Lyon Milner, Winifred Ethel Penn-Gaskell, Richard Arthur Rubinstein (from Student), Robert David Nigel Saunders (from Student).

ACKNOWLEDGMENTS

The Council acknowledge with grateful thanks the following gifts: Three 9 mm. films of aircraft, taken about 1912, from A. M. Desoutter, F.R.Ae.S.; copies of Annual Reports of the Aeronautical Society of Great Britain from 1883-1884, from Sir Francis McClean, A.F.C., F.R.Ae.S.; and back numbers of the Journal from D. D. Jones, Associate, R. S. Sowter, Student, and L. A. Wingfield, Associate.

ADDITIONS TO THE LIBRARY

N.A.C.A. Technical Notes

1389—*Design charts for flat compression panels having longitudinal extruded Y-section stiffeners and comparison with panels having formed z-section stiffeners. Norris F. Dow and W. A. Hickman.*

1388—*Performance of an axial-flow compressor rotor designed for a pitch section lift coefficient of 1.20. L. J. Herrig and S. M. Bogdonoff.*

1387—*A preliminary correlation of the behaviour of water rudders on seaplanes and flying boats. F. W. S. Locke.*

1384—*A review of boundary layer literature. Neal Tetervin.*

1383—*Theoretical study of air forces on an oscillating or steady thin-wing in a supersonic main stream. I. E. Garrick and S. I. Rubinov.*

1382—*Distribution of wave drag and lift in the vicinity of wing tips at supersonic speeds. John C. Evvard.*

1381—*Numerical evaluation of mass-flow coefficient and associated parameters from wake-survey equations. Norman F. Smith.*

1379—*Wind-tunnel investigation of the effect of power and flaps on the static lateral stability and control characteristics of a single-engine high-wing airplane model. John R. Hagerman.*

1378—*Preliminary investigation at low speed of downwash characteristics of small-scale sweepback wings. P. E. Purser, M. L. Spearman and W. Bates.*

1377—*Wind-tunnel investigation of unshielded horn balances on a horizontal tail surface. John G. Lowry and Stewart M. Crandall.*

1374—*Experimental studies of the knock-limited blending characteristics of aviation fuels. II. Investigation of leaded paraffinic fuels in an air-cooled cylinder. Jerrold D. Wear and Newell D. Sanders.*

1373—*Charts for the determination of supersonic air flow against inclined planes and axially symmetric cones. E. W. Moeckel and J. F. Connors.*

1372—*Some considerations on an airfoil in an oscillating stream. J. Mayo Greenberg.*

1368—*Theoretical and experimental data for a number of N.A.C.A. 6a-series airfoil sections. Laurence K. Loftin, Jr.*

1338—*Propeller-efficiency charts for light airplanes. John L. Crigler and R. E. Jaquis.*

1324—*Interaction between the spars of semi-monocoque wings with cutouts. N. J. Hoff, Harry Case and Harold Liebowitz.*

1312—*A comparative study of weights and sizes of flat-plate exhaust-gas-to-air heat exchangers with and without fins. Thorval Tendeland and Charles P. Steinmetz.*

1301—*A method for calculating the heat required for the prevention of fog formation on the inside surfaces of single-panel bullet-resisting wind shields during diving flight. James Selna and J. E. Zerbe.*

1300—*The effects of aerodynamic heating and heat transfer on the surface temperature of a body of revolution in steady supersonic flight. Richard Scherrer.*

1261—*Effect of variables in welding technique on the strength of direct-current metal-arc-welded joints in aircraft steel. I. Static tension and bending fatigue tests of joints in S.A.E. 4130 steel sheet. C. B. Voldrich and E. T. Armstrong.*

The following reports have also been received:—

British Intelligence Objectives Sub-Committee

B.I.O.S. Final Report No. 1339.
F.I.A.T. Final Report No. 1034.
B.I.O.S./J.A.P./P.R./887.

National Luchtvaarlaboratorium Amsterdam

Rapport V.1398.

Australian Council for Scientific and Industrial Research

Report SM 92.

Smithsonian Miscellaneous Collections

Vol. 107, Nos. 9 and 10.

B.b.6—Le Vol. Vertical. Lt.-Col. Lamé. Blondel la Rougery, Paris. 1934.

D.a.97—*Preliminary report of the special advisory committee on private flying. M.C.A.P.* 31. *Ministry of Civil Aviation. H.M.S.O.* 1947.

E.c.33—Light Metals in Structural Engineering. L. Dudley. Temple Press. 1947.

EE.h.31—Modern Gas Turbines. Arthur W. Judge. Chapman & Hall. 1947.

EE.h.32—B.C.A.S. Handbook of Pneumatic Equipment. British Compressed Air Society. 1947.

G.e.F.19—Rubber in Engineering. Ministry of Supply. H.M.S.O. 1946.

G.e.F.20—The Fundamentals of Rubber Technology. Eight lectures delivered at Newton Heath Technical School. Imperial Chemical Industries. 1947.

G.e.J.28—Advance copies of papers to be presented at a symposium on internal stresses in metals and its alloys. Institute of Metals.

L.d.116—*Notices to Airmen. Nos.* 290, 291, 292, 293, 294, 295, 296, 297, 298, 299, 300, 302, 303, 304, 305, 306, 307, 309, 310, 311, 312, 313, 314, 315, 316, 317, 318, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 330, 331, 332, 333.

Q.c.55—The Teaching of Aeronautics in High Schools. Civil Aeronautics Administration and American Council of Education. McGraw Hill. 1947.

X.e.68—Bristol Engineering Directory, 1947. Bristol Engineering Manufacturing Association. 1947.

A.R.C. Reports and Memoranda

2127—*Design of suction slots. A. Fage and R. F. Sargent.*

2095—*The present basis of axial flow compressor design. Part I. Cascade theory and performance. A. R. Howell.*

2048—*Flutter at high incidence. Mary Victory.*

2168—*Drag analysis of performance obtained at aircraft and armament experimental establishment on various aircraft, with particular reference to slipstream corrections. W. J. D. Annand and A. K. Weaver.*

2163—*The distribution of shear in a tapered fuselage—Strain measurements on Barracuda V. D. C. Allen.*

2100—*Stress concentration due to four-point fixing at front end of monocoque fuselage, theoretical analysis. M. Fine and D. Williams.*

N.A.C.A. Technical Notes

1420—*An application of lifting-surface theory to the prediction of angle-of-attack hinge-moment parameters for aspect ratio* 4.5 *wings. Arthur L. Jones, M. G. Flanagan and Loma Sluder.*

1427—*Laboratory investigation of ice formation and elimination in the induction system of a large twin-engine cargo aircraft. W. D. Coles.*

1391—*Icing properties of noncyclonic winter stratus clouds. W. Lewis.*

1423—*The stability derivatives of low-aspect-ratio triangular wings at subsonic and supersonic speeds. H. S. Ribner.*

1418—*Investigation of the pressure-loss characteristics of a turbojet inlet screen. J. L. Lankford.*

1421—*Effect of variation in diameter and pitch of rivets on compressive strength of panels with z-section stiffeners. Panels of various lengths with close stiffener spacing. Norris F. Dow and W. A. Hickman.*

1249—*A study of piston-ring friction. J. C. Livengood and Chapin Wallour.*

1355—*A study of metal transfer between sliding surfaces. B. W. Sakmann, N. Grossman and John W. Irvine.*

1429—*The effects of yawing thin pointed wings at supersonic speeds. J. C. Evvard.*

1426—*Method of designing vaneless diffusers and experimental investigation of certain undermentioned parameters. W. Byron Brown and G. R. Bradshaw.*

1422—*Experimental and calculated characteristics of three wings of N.A.C.A. 64-210 and 65-210 airfoil sections with and without 2 per cent. washout. J. C. Sivells.*

1417—*High-speed wind-tunnel tests of an N.A.C.A. 0009-64 airfoil having a 33.4 per cent. chord flap with an overhang 20.1 per cent of the flap chord. D. B. Stevenson and A. A. Adler.*

1431—*Investigation of the aileron and tab of a spring-tab lateral control system in the Langley 19-foot pressure tunnel. O. J. Deters and R. T. Russell.*

The following reports have also been received:—

British Intelligence Objectives Sub-Committee

B.I.O.S. Final Reports No. 1210, Item No. 30; No. 1494, Item No. 25; No. 1574, Item No. 22.

F.I.A.T. Final Reports Nos. 977, 623, 614, 948, 1034, 987, and 637.

B.I.O.S./J.A.P./P.R./131 and 887.

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A.C.A. 30, 31, and 32.

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JAN 17 '48

THE ROYAL AERONAUTICAL SOCIETY

ACTIVITIES
of the
GRADUATES' AND STUDENTS' SECTION

December 1947

It is proposed to give, as far as possible, a monthly account of the activities of the Graduates' and Students' Section.

For various reasons many Graduates and Students are unable to play an active part in the Section's activities. Many live too far afield while others are occupied in studying. The Section exists, however, to promote the interests of all Graduates and Students, and the Section Committee considers and makes recommendations upon matters affecting Graduate and Student members of the Society.

Requests have been received from members, who have been unable to attend lectures, for the publication of lectures read before the Section. Unfortunately, the paper shortage prevents the publication in full, either in the Journal or in pamphlet form, of all lectures delivered to the Section. It is intended to issue a short report in these notices of papers delivered to the Section in an endeavour to meet these requests.

Work of Committee

The Section Committee has met three times since its election in March 1947. In addition to arranging visit and lecture programmes covering the period up to May 1948, the Committee has submitted recommendations on matters concerning the new Associate Fellowship examination syllabus and the proposed new membership fees. The Committee has also suggested that the Society's all-day discussions be held on a Saturday.

Dance

The second annual dance was held at the Royal Hotel, Woburn Place, on Friday 17th October. It was attended by the President, Dr. Roxbee Cox, and Mrs. Roxbee Cox, who were the guests of the Section. It is regretted that the dance was not as well attended as last year, and it is hoped that there will be greater support for events of this kind in future.

Lectures

A lecture on "Maintenance Difficulties in the Field" was delivered by Mr. M. J. Kemper on Tuesday 4th November, and it is published in full in the December Journal.

On 21st October a lecture on " Rocket Propulsion and Interplanetary Flight " was given at which some 90 people were present. A brief account of the lecture is given below.

" Rocket Propulsion and Interplanetary Flight "
by Mr. A. V. Cleaver, A.R.Ae.S.

A lecture on " Rocket Propulsion and Interplanetary Flight " was read before the Section on 21st October by Mr. A. V. Cleaver, A.R.Ae.S., Special Projects Engineer of the de Havilland Engine Co. Ltd. Mr. J. W. F. Housego was in the chair.

P.T.O.

Mr. Cleaver began by defining a rocket and outlined its main characteristics. It has a jet of small mass and high velocity; it gives a thrust which is almost independent of altitude; it has a high thrust-weight ratio and is simple; it has a high thermal efficiency but a low propulsive efficiency unless the flight velocity approaches the jet velocity. Combustion temperatures are high, presenting difficult cooling problems.

A number of lantern slides were shown, illustrating the development of the rocket from the early Chinese fire-arrows, through the small experimental rockets developed in the 1930's in Germany and America, to the German rocket-propelled fighters, anti-aircraft missiles and V.2's and the British rocket projectiles. At the end of the second world war, one third of all German scientists and technicians were engaged upon development. Led by that able, ambitious pioneer of the rocket, Von Braun, they had designed a two-stage trans-Atlantic rocket with a take-off weight of 100 tons.

The applications of the rocket were mentioned. Some of these, the use of rockets for assisted take-off, for boosted thrust in flight, for guided and unguided missiles, were already familiar. In addition, the Americans were using rockets for research into conditions in the upper atmosphere, the troposphere and the sub-stratosphere, up to heights of about 240 miles. The most intriguing use of rockets, however, was in the field of interplanetary flight, which would, in the lecturer's opinion, be a practicable possibility, in 50 years, at the present rate of technical progress.

It is the rocket that will make interplanetary flight theoretically possible. To obtain the necessary range it can be shown that the jet velociy and the mass ratio (ratio of take-off mass to final mass) must be high. The use of the step rocket would be one way of increasing the mass ratio. To escape from the gravitational field of the earth (or any other body), a certain velocity, known as the escape velocity, must be attained. The escape for the earth was about seven miles per second (25,000 m.p.h.), and once this was attained, the rocket could become either a spaceship or an artificial satellite; the latter could be used as an observation station or a radio relay station.

Chemical fuels could only give a maximum velocity of about three miles per second, and to attain higher velocities, atomic means of propulsion would have to be used. Two methods were suggested: the first was to heat a stream of inert gas by means of an atomic pile and to eject this stream of hot radio-active gas as a jet; the second method was to inject streams of fissile material into a mixing chamber together with the inert gas and again to eject the hot mixure. The dangers of radio-activity were obvious and chemical rockets would have to be used within the atmosphere, the atomic rocket being used when the short distance to the troposphere had been covered.

There were many problems to be overcome in the field of comfort—air supply, cooling, food, Zero gravitational force, etc.—but the more difficult one of propulsion must be overcome first.

Mr. Cleaver then replied to a number of questions, and the Chairman ended the meeting by calling for a vote of thanks to the speaker for his most interesting lecture.

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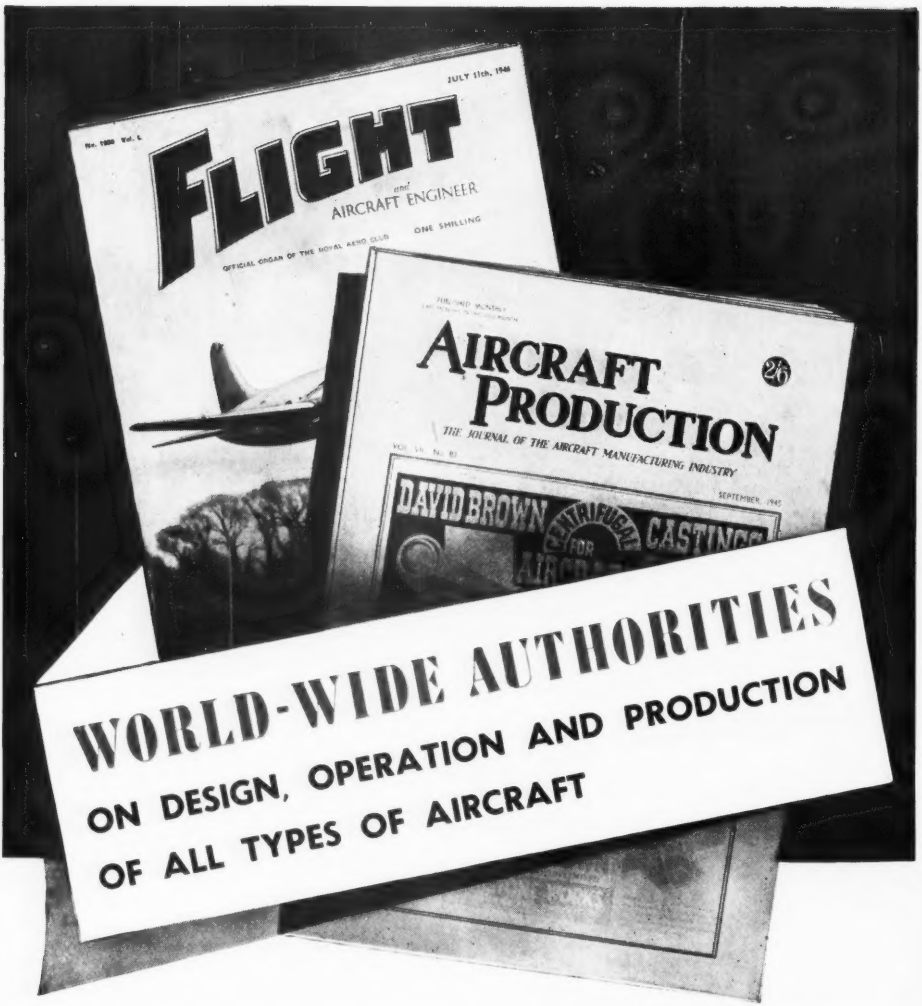

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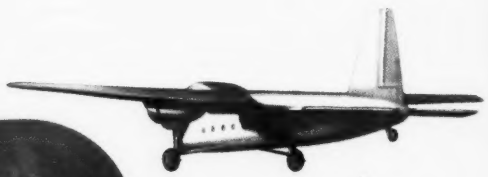

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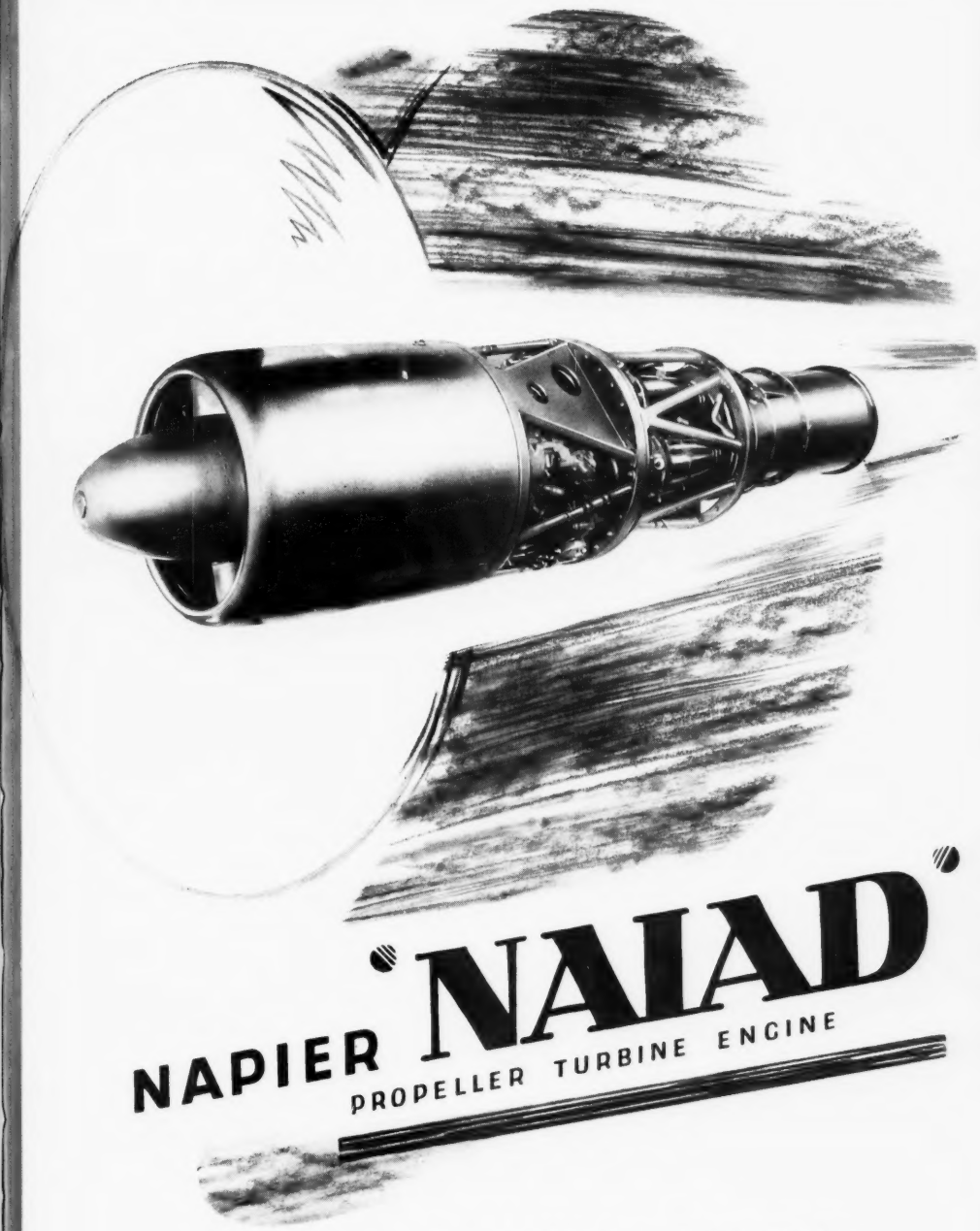

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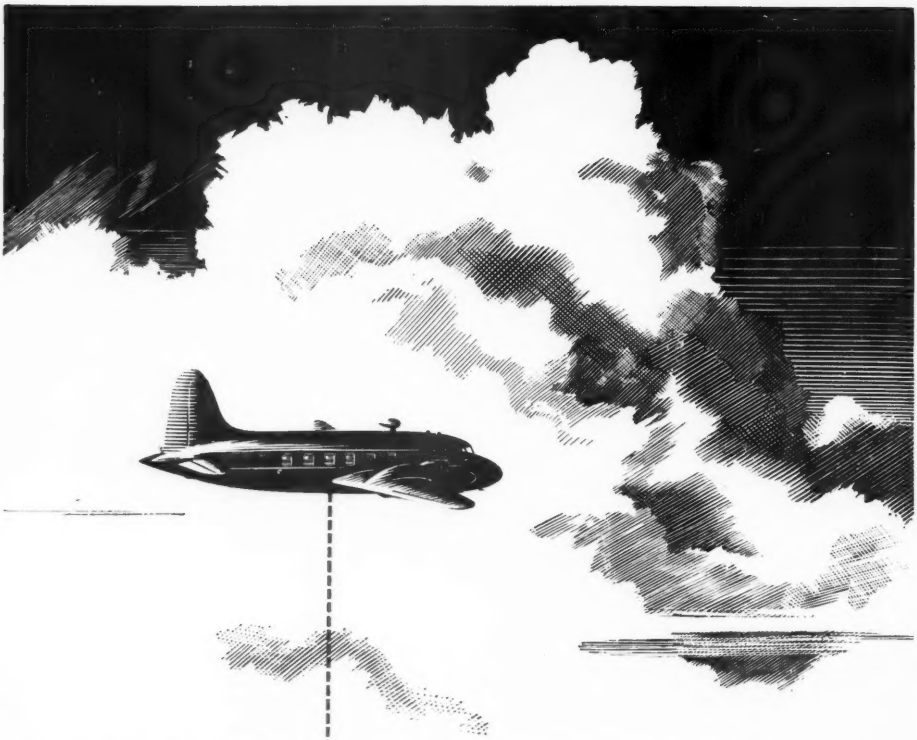

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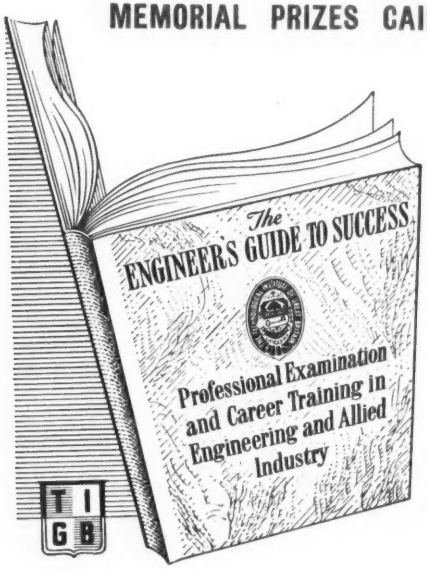

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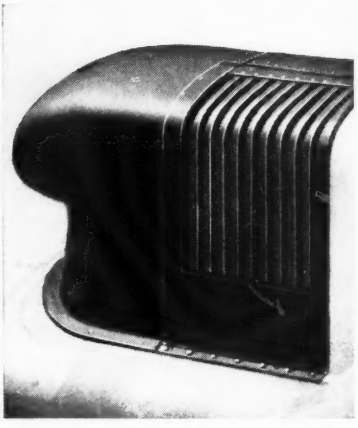

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MATHEMATICS

Only very simple symbols and formulas should be typewritten. All others should be written carefully by hand in ink. Ample space for marking should be allowed above and below all equations. Greek letters used in formulas should be designated by name in the margin.

The difference between capital and lower-case letters should be clearly shown; care should be taken to avoid confusion between zero (0) and the letter o, between the numeral one (1) and the letter l, between alpha and a, kappa and k, mu and u, nu and v, eta and n.

All subscripts and exponents should be clearly marked, and dots, bars, and so on, over letters should be avoided as far as possible.

Square roots of complicated expressions should be written with the exponent $\frac{1}{2}$ rather than with the sign $\surd$.

Complicated exponents and subscripts should be avoided. Any complicated expression that recurs frequently should be represented by a special symbol.

Unless an abbreviation is one recognised as standard practice, both in this and other English-speaking countries, for example, b.h.p. for brake horse power, the meaning should be given in full on its first use.

THE ROYAL AERONAUTICAL SOCIETY

A meeting of the Society was held at the Institution of Civil Engineers, Great George Street, Westminster, London, S.W.1, on Thursday, 9th October, 1947, at which a number of the Society's medals were awarded and the new President was inducted before the 738th lecture by Mr. W. M. Widgery was read before the Society.

Sir Frederick Handley Page, C.B.E. (Retiring President), occupied the Chair during the early part of the proceedings.

Awards

The President said that it was a pleasing duty, on the last occasion on which he would preside over the deliberations of the Society before resigning office, to hand to the recipients their respective Medals and Prizes.

The Silver Medal of the Society, awarded for some advance in aeronautical design, was presented to Mr. W. G. Carter, C.B.E., F.R.Ae.S., Chief Designer, Gloster Aircraft Co. Ltd., for his work on the development and design of jet-propelled aircraft.

The Simms Gold Medal, awarded annually for the best paper read in any year before the Society on any science allied to aeronautics, was presented to Professor Leslie Aitchison, D.Met., B.Sc., F.R.I.C., M.I.A.E., F.R.Ae.S., Professor of Industrial Metallurgy at the University of Birmingham, for his paper on "Aeronautics and the Metallurgist."

The George Taylor (of Australia) Gold Medal, awarded for the most valuable paper submitted or read during the previous session, was presented to Professor A. R. Collar, M.A., D.Sc., F.R.Ae.S., Professor of Aeronautical Engineering at the University of Bristol, for his paper, "Aeroelastic Problems at High Speed."

The Wakefield Gold Medal, awarded to the designer of any invention or apparatus tending towards safety in flying, and open to members or non-members, was awarded to Mr. Edwin Link, the inventor of the Link Trainer.

Mr. Link was unable to be present, and the Medal was formally presented by the President to Mr. L. Satterthwaite, Civil Air Attaché at the American Embassy. The presentation to Mr. Link will be made in New York later in the year.

Sir Frederick Handley Page, in presenting the Medal, said it was nice that, so soon after the successful Anglo-American Aeronautical Conference held in London, the Society was able to make an award to one of the aeronautical brethren across the seas.

The R.38 Memorial Prize, offered annually for the best paper received by the Society on some subject of a technical nature in the science of aeronautics (preference being given to papers relating to airships), was awarded to Mr. J. K. Hardy, of the Royal Aircraft Establishment, for his paper on "The Protection of Aircraft Against Ice."

The Edward Busk Memorial Prize, offered annually for the best paper received by the Society on some subject of a technical nature in connection with aeroplanes (including seaplanes), was awarded to Mr. J. Smith, C.B.E., F.R.Ae.S., Chief Designer of Vickers-Armstrongs, Ltd., for his paper on "The Evolution of the Spitfire."

Induction of the New President

Sir Frederick Handley Page then formally invested his successor, Dr. H. Roxbee Cox, with the Presidential badge of office, invited him to occupy the Chair, and wished him every success in his conduct of the affairs of the Society.

Dr. H. Roxbee Cox, on assuming the Chair, paid tribute to Sir Frederick, and referred to the gift to the Society of the new Presidential badge. The Society was the oldest aeronautical society in the world, 82 years old, but it had not developed many picturesque ceremonies or traditions. That fact had been perceived by Sir Frederick and, with his usual good taste and munificence, he had seen to it that later on the members of the Society would be able to look back and appreciate that they had a tradition, and a very pleasant one, to follow, a tradition whereby the cares of office were handed over in a symbolical, as well as in other, ways.

They would all regret that the occasion was the last on which Sir Frederick Handley Page would occupy the Chair as President. The Members of Council had deeply appreciated for a long time the way in which he had guided the Society's affairs and the help and direction he had always given. All who attended the meetings of the Society recognised also the excellent way in which he had conducted the business of the meetings, always with a touch of humour which had been appreciated almost as much as the technical discussions.

He invited the meeting to express the thanks of the Society for all that Sir Frederick had done. The vote of thanks was carried with enthusiasm.

Dr. Roxbee Cox then introduced Mr. Widgery, who presented his paper.

THE ROYAL AERONAUTICAL SOCIETY

PRESSURISATION AND CABIN AIR CONTROL

by

W. M. WIDGERY, F.R.Ae.S.

Mr. Widgery obtained technical training at the Polytechnic, Regent Street, London and practical training with Handley Page Ltd., remaining with that company as a Technical Assistant. Since 1923 *he has been with Westland Aircraft Co., working first on aerodynamic testing and research and, from* 1926 *until* 1936, *in close association with Professor G. T. R. Hill, on the aerodynamic problems of tailless aircraft. In* 1938 *he was appointed Chief Experimental Engineer and in* 1940 *began work on the special problems of high altitude flight of the Westland Welkin, evolving automatic control waves and other specialised equipment for pressurised cabins which have since become standard for all British aircraft. Since* 1944 *he has been responsible for research and development on the design and operation of pressurised cabins for civil aircraft. In* 1946 *he was appointed Chief Engineer of Normalair Ltd., the company associated with Westland Aircraft Ltd.*

IN the opinion of the writer the bald name "Pressurisation" gives a crude and misleading picture of the developments which are now in hand and both he and the organisation to which he belongs, prefer to speak of "Cabin Air Control," as this name gives a clearer picture of the scope of the developments which are the subject of this paper.

At the outbreak of the war the evolution of passenger-carrying aircraft had reached a stage where a great deal of attention was desirable for the comfort of passengers and, in those passenger-carrying aircraft which have subsequently gone into service, it is fair to describe Pressurisation as a development directed almost entirely towards the greater comfort of the occupants. Although modern developments are rapidly carrying us into operation at much greater altitudes, where safety will assume far greater importance, up to the present, and probably for some little while to come, the problems of Pressurisation, safety and comfort will be bound up inextricably. It is well known that during the late war many military aircraft were pressurised to enable their crews to maintain fighting efficiency, and that a beginning had been made in the civil field by, for example, the Boeing and Curtiss Companies in the U.S.A.

Of necessity, because mountain ranges must at times be crossed, and also in the interest of economy, civil aircraft were operating at considerable altitudes before the outbreak of the late war, and the necessity for wearing oxygen masks constituted a serious handicap when in competition with older forms of transport, since the majority of passengers carried in civil aircraft have deep-rooted psychological objections to the wearing of masks. It is not the purpose of this paper to enter the field of physiology, but we may well make a brief résumé of the fundamentals as they affect the engineer.

Mankind, in common with all animals, has need of a continuous supply of oxygen which is absorbed into the blood *via* the lungs; the requirements vary from one individual to another and are greatly affected by the strenuousness of the activities to be supported. The quantity of oxygen which may be transferred to the blood by the lungs varies with

the partial pressure of the oxygen in the atmosphere, and this may be artificially increased by enriching the local atmosphere with oxygen which is breathed into the lungs through a mask, the actual amount of oxygen administered being varied to suit the altitude. At an altitude in the neighbourhood of 43,000 ft. the individual is unable, because of the decreasing total pressure in the lungs, to obtain sufficient oxygen even when the local atmosphere consists entirely of oxygen. This sets a strict limit on the operational height without pressure, even for military aircraft in which crew comfort is not the criterion. Moreover, at very low pressures subjects are liable to suffer from the painful and distressing complaint known as Caisson disease or "the bends." This complaint is symptomised by severe muscular pain and cramp attributable to the release of nitrogen absorbed by the blood at higher pressure. Although Service pilots have made a large number of operational and research flights at altitudes up to 45,000 ft. these were only done at considerable discomfort to the personnel. Fortunately the composition of the atmosphere varies but slightly with increasing altitude so that ground level or any other chosen low altitude atmospheric condition can be restored by increasing the pressure within the cabin.

One important exception to the statement about the composition of the atmosphere is that the moisture content falls off rapidly at the greater heights, but this aspect of the problem is dealt with separately later.

Up to the present time, civil aircraft have not been operated above 25,000 ft., at which height oxygen alone, from the physiological point of view, would be a satisfactory alternative to Pressurisation for the majority of people, so that we may fairly say that Pressurisation has been developed purely to give greater comfort.

CHOICE OF PRESSURES

The correct choice of pressure is influenced by a number of important considerations which, in general, are similar for civil and military aircraft. There is one fundamental difference; on civil aircraft we must ultimately rule out the possibility of sudden failure of the pressure, while with military machines we must assume that complete failure of the pressure system is likely to occur at any moment because of enemy action.

On the British military aircraft which were pressurised during the late war, the ill effects of a sudden loss of pressure were minimised by confining the pressure to that minimum vital to maintain the fighting efficiency of the crews, and as a natural consequence they were compelled to wear oxygen masks when flying at the greater altitudes. In fact, the wearing of oxygen masks in itself constituted the real safeguard against sudden failure, since the only action required of the pilot was the adjustment of oxygen flow to suit the resulting altitude in the cabin. The simple apparatus employed automatically varied the cabin pressure with increasing altitude, but did not permit variation of cabin pressure in flight, although the pilot could eliminate pressure entirely. A most desirable improvement on this is to give the crew full control of the operating pressure so that this may be varied to suit cruising or combat conditions.

Although a low cabin pressure gives a large measure of protection against the ill-effects of oxygen starvation, there is another risk which will attend flight at very great altitudes, and that is explosive decompression. The physiology of explosive decompression is outside the scope of this paper and it must suffice to note that the seriousness of the consequences is a function of time and expansion ratio. As, obviously, the time for decompression is closely related to the volume of the cabin, it should be noted that aircraft with small cabins (*e.g.*, fighters) should be flown at the minimum permissible pressure in combat, but where the cabin has a large volume, as in a civil transport or bomber, serious physiological consequences are unlikely to result from sudden release of

pressure caused by the type of failure which may be expected (*e.g.*, blowing out of an observation panel).

There seems little doubt that the ideal pressure for civil aircraft is that which is sufficient to maintain ground level conditions up to the operational ceiling, as the pressure within the cabin will then remain unchanged throughout the duration of the flight and as a result, the pilot will be free to climb or descend at any rate which is desirable for other reasons.

There is excellent agreement among the physiologists that unselected passengers may be subjected without undue risk to a reduction of pressure equivalent to that experienced at a height of 8,000 ft. and advantage was taken of this finding when setting the pressure for the civil aircraft now going into service as limited experience, and the natural wish to keep any additional weight to a minimum, led to the choice of as low a pressure as feasible.

With an operational ceiling of 25,000 ft. the necessary pressure is 5½ lb. per sq. in. compared with 9.4 lb. per sq. in. to maintain ground level conditions (Fig. 1).

MAIN CONSIDERATIONS

Installations in military aircraft, having been produced under stress of war, were perforce of the simplest. We shall find, however, on examining the basic layouts for military and civil installations, that the latter have developed logically from the former. Naturally, refinements designed purely to give greater comfort to the air crews have found little or no place in the war-time installations. It may now be expected that the knowledge and experience gained with civil installations will be carefully reviewed so that the air crews of fighting aircraft may operate in the best possible conditions. This does not necessarily mean that every refinement incorporated in civil installations will find a place in fighting aircraft, but it will become clear that the conditions of operation of the two types will automatically lead to similar require-

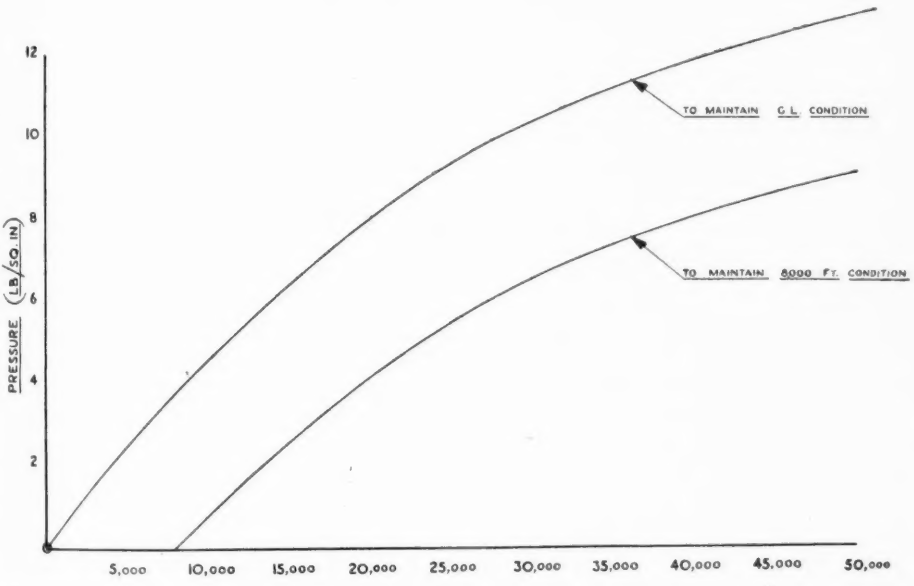

Fig 1.

ments in both cases, for unless undue penalties are imposed by way of increasing weight or decreasing performance, there seems no good reason why the crews of service aircraft should suffer avoidable discomfort. Therefore, it is evident that we should review the standards which are becoming accepted for civil aircraft and see to what extent they have been met, or are likely to be, in military machines.

Fresh air supply

This is to be 1 lb. per person per minute in normal cruising conditions with duplication of blowers. (Minimum .6 lb. with one blower out of action.) The single type of blower has been common to all the pressurised British fighters up to now, and this delivers 5 lb. of air per minute at 40,000 ft. The criterion in this case is the minimum flow necessary to neutralise small leaks rather than the physiological needs of the pilot.

Rates of change of pressure

There is now considerable data on the rates of change of pressure to which passengers may be subjected without discomfort, and it is generally agreed that, awake, they are not inconvenienced by rates of change up to the equivalent of 300 ft. per minute, but when asleep they may suffer serious discomfort if the rates of change are in excess of 150 ft. per minute. This means that the actual rates of change in lb. per sq. in. are .157 lb. per sq. in. at G.L. and .079 respectively.

It would appear unnecessary to set such close limits on the rates of change for air crews, but the same equipment which is available for civil aircraft will be available for military aircraft. It should be borne in mind that aircraft of the future may have such great rates of climb and descent that the comfort unless suitable precautions are taken. crews may be subjected to intolerable dis-

Temperature control

The temperature within the cabin is to be controllable within close limits. To maintain low temperature with higher ambient temperature necessitates refrigeration.

Humidity

The humidity when flying at altitude is to be maintained at a minimum of 20 or 30 per cent. This necessitates the carrying of water, but the extra weight would probably be well justified by the resulting improvements in crew comfort and efficiency. Care must be taken when reducing the pressure, for instance from cruising to combat conditions, to ensure that misting shall not occur. This may entail a limit to the speed with which pressure is reduced if humidification apparatus has been in use immediately before. The reduction of humidity in regions of high humidity requires refrigeration or other apparatus.

Safety precautions

It is a requirement that every piece of vital equipment shall be fully duplicated and it seems logical that the same safeguard should apply to military aircraft, although this has not always been the case in the past.

While the designs of military aircraft were being evolved during the war the precautions to be taken were arrived at by consultation between the designers and the M.A.P. Similar conditions prevailed during the evolution of the civil aircraft now going into service, but since that time these requirements have been reviewed and rationalised and are now set out in the Civil Airworthiness Handbook issued by the Air Registration Board, Section D22, and it is useful to note that these requirements are so framed that aircraft designed in accordance with them will also obtain approval of I.C.A.O.

As regards the actual pressure cabins these regulations are framed to prevent:—

(*a*) Damage to the cabin by excessive pressure.
(*b*) Crushing of the cabin during rapid descent.
(*c*) Sudden loss of pressure.

The ways in which these requirements can be met are necessarily limited, although naturally variations will exist. Apart from structural strength the present equipment itself is designed to give adequate safeguards as follows:—

(*a*) Provision of generous safety valves of simple and robust design.

(*b*) Provision of inwards relief valves which will admit air if the pressure within the cabin sinks below the external pressure by more than a defined margin.

(*c*) The duplication of the complete air supply system, including the cabin blower, and by a specially designed discharge valve to which further reference will be made. To be effective the duplication of air supply must be carried right up to the cabin wall, because not only must we guard against failure of the blower to deliver air but, also, precautions must be taken to prevent escape of air in the event of a duct becoming damaged. This risk is guarded against by the provision of non-return valves at the cabin wall.

Loss of pressure caused by the failure of a discharge valve has been guarded against by constraining the escaping air to pass through two valves in cascade arranged in a common casing. The design of this unit is such that failure of one component has no appreciable effect on the pressure at which the cabin is maintained.

Control of pressure

In all the systems known to the writer the cabin pressure is controlled by regulating the rate of discharge of air from the cabin. The discharge valves in use are automatic and although it is customary to exercise some control over the incoming air, within the limits set by leakage and the capacity of the valve, the cabin pressure is independent of the rate of input.

The design and construction of discharge valves can vary within extremely wide limits, but in principle they bear a marked similarity. In every case the mechanism is divisible into two essential parts, the Discharge Valve proper, and some sensitive mechanism which responds to changes of atmospheric pressure and cabin pressure; the two parts being linked together so that the passage through the discharge valve is opened and closed in response to impulses from the sensitive mechanism. The essential components of the sensitive mechanism in every case take the form of capsule packs or bellows some of which are exhausted thus, in effect, constituting altimeters, while the others are connected on one side to the cabin and on the other to the outside air, so that in effect they are pressure gauges. The link between the sensitive mechanism and the discharge valve may take several forms. For example, it may be pneumatic, or electric, or hydraulic. The discharge valve itself may take a multiplicity of forms; one well-known American type consists essentially of a large tapered needle moving in an orifice, while the type commonly used on British aircraft, produced by the writer's organisation, employs a flexible diaphgram or bellows, the face of which constitutes the moving part of a variable orifice.

A full description is to be found elsewhere.

BASIC LAYOUT

We have seen how the requirements of pressurisation, with little reference to air conditioning and comfort, can be met and while engine-driven compressors are the rule, it is unlikely that there will be any radical change in the simple arrangements outlined. However, even in the simple military installations of the war period it was found necessary to introduce some refinements. For example, on the Westland Welkin, which was the first aircraft in this country to be designed *ab-initio* for pressure, a silencer was fitted between the blower and the cabin, and after some preliminary flying it was found necessary to introduce a measure of air cooling, which was achieved by allowing jets of air to impinge on the silencer casing.

Figure 2 shows the essential parts of the system used on this aircraft which may be looked upon as typical for the type. The blower is of the Rootes type developed by Sir George Godfrey & Partners, and the primary use of the filter which precedes it is to exclude dirt and dust which cause rapid deterioration of the blower. After leaving the blower the air passes through the silencer and thence through the inwards relief and spill valve into the cabin. The pilot had no means of varying the pressure in flight as the discharge valve was pre-set to have characteristics as shown in Fig. 3. He could dispense with pressure entirely by deflating the coupé seal. The aircraft was fitted with a sliding coupé and a great deal of development went into the production of a satisfactory seal, but the final article, produced with the assistance of the Dunlop Rubber Co. Ltd., was found to be entirely satisfactory and very reliable.

Even in so simple an article a great deal of experiment is required. For example, it was easy to design a seal which was satisfactory for the straight portion where the coupé slides upon the fuselage, and not very difficult to design other systems which worked satisfactorily over the curved portion of the hood, but attempts to join various portions of such a composite seal were invariably attended by failure.

The final version needed only to be inflated to slight pressure, and in the absence of leaks remained tight for an indefinite period. It was deemed wise to have some system providing for continuous inflation, as in this way the effects of punctures caused by damage or enemy action would be minimised. Although the writer knows of no reliable data from aircraft which had been in action, it is of interest to note that in no case had a report of puncturing due to normal wear and tear come to his notice.

One or two points of great interest came to light during flight trials of the Welkin pressure system. Considerable pains were taken in lagging the fuselage to protect the pilot from cold, but it was found that he suffered from excessive heat even at great heights, and it was found necessary to introduce a measure of cooling. Another phenomenon showed itself when the engines were started up from

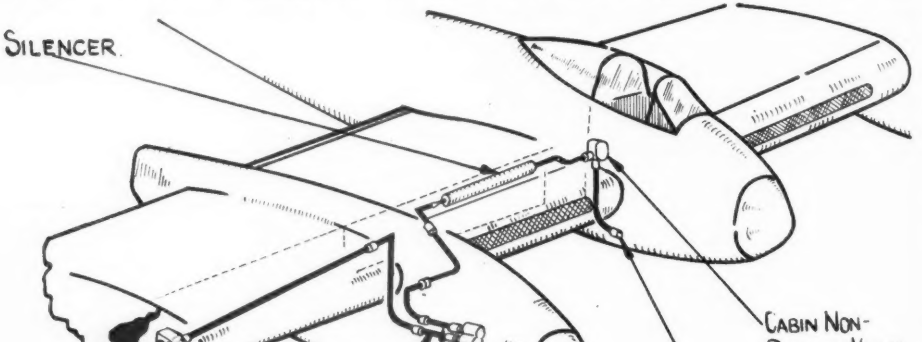
SILENCER.
CABIN NON-RETURN VALVE MOUNTING BEHIND BULLET-PROOF BULKHEAD
BLOWER DELIVERY FROM BLOWER.
VOKES AIR FILTER.
CONNECTION FOR GROUND TEST BLOWER.
SUCTION FROM AIR FILTER TO BLOWER.

FIG. 2.

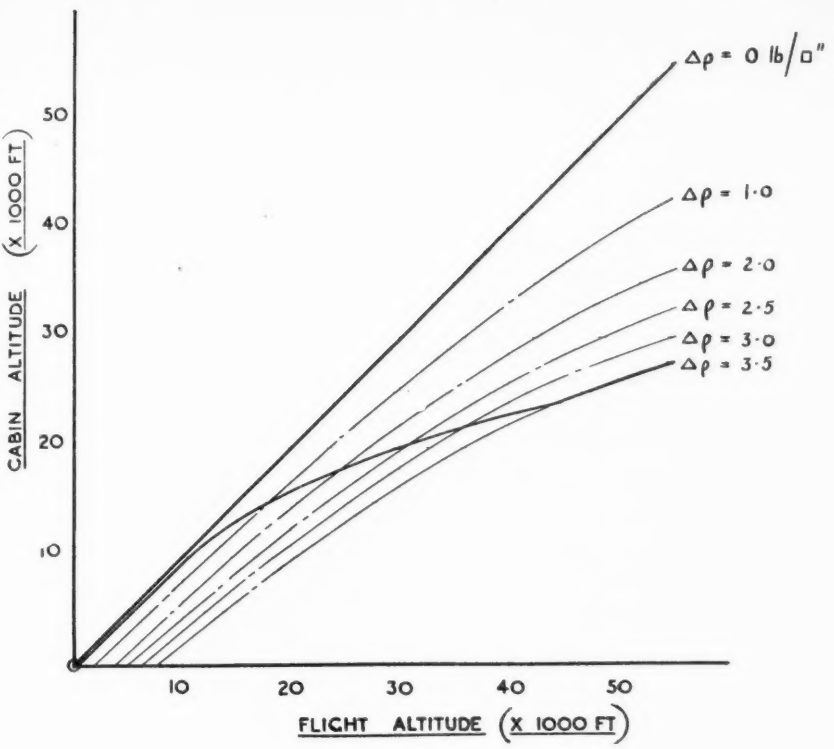

Fig. 3.

cold in the early morning. Apparently water vapour from the small radiator which heated the air for the sandwich windscreen and hood ascended into the sandwich and condensed on the panels producing misting. This seems to have been attributable to small leaks in the heater and although the misting quickly disappeared when the aircraft was taxied, because of the flow of air through the sandwich, a complete cure was not effected. At approximately the same period of time the Spitfire, Mosquito and Meteor appeared as pressurised aircraft, considerable skill and ingenuity being displayed in the conversion of the first two.

The Meteor is of special interest because the air supply for the cabin is obtained by bleeding the compressor of the jet instead of by employing a separate blower.

CIVIL AIRCRAFT

Early in 1944, as a result of the recommendations of the Brabazon Committee, considerable attention was focused on the design of pressurised civil aircraft.

The experience obtained during the design and operation of the military aircraft, to which reference has been made, was drawn upon to the full but the whole problem of providing comfort and the requisite degree of reliability in civil aircraft is complex, although because of the nature of the problems and the apparatus available, the variations of basic layout are somewhat limited. There are a number of aspects of the problem, each of which requires attention before considering a typical layout.

Heating

Unfortunately the methods commonly employed for buildings have been ruled out for aircraft on the score of weight, and the heat necessary to maintain a comfortable temperature in the cabin has been introduced by raising the temperature of the circulating air. There is a practicable limit beyond which the temperature of air cannot be raised without risk of causing undesirable smells because of " roasting " of dust and organisms in the air. This temperature is in the neighbourhood of 140°F. and a careful analysis must be made to ensure that sufficient heat enters the cabin without this temperature being exceeded. The necessary amount of heat is very much bound up with the effectiveness of the lagging and some years ago, when the basic design of aircraft now flying was decided, it was deemed wise to set additional air in motion to avoid exceeding the safe temperature. This has been accomplished by introducing internal circulating fans which provide a flow of air to augment that delivered by the blower. This arrangement is only effective in reducing the air temperatures if the heater is so placed that the re-circulating air passes through it, in addition to that entering from the blowers.

The lightest and most efficient heaters available at the present time are of the petrol burning variety. (Heat transferred to circulating air amounts to approximately 80 per cent. of the heat of combustion.) Objections have been raised to internal stowage of these heaters because of the fire risk involved. From this point of view it is eminently desirable that the heaters should be so placed that simple precautions can be taken to isolate them in emergency.

Fortunately combustion takes place at atmospheric pressure so that a leak through the wall of the heat exchanging surfaces results only in a loss of cabin air by way of the combustion space.

The heaters at present in use cannot readily be operated when the aircraft is on the ground, as a forward facing scoop is used to supply the air for combustion when the aircraft is in flight.

The heat output required is largely dependent upon the efficacy of the thermal insulation, but may reach a figure of 100,000 B.Th.U.s per hour for an aircraft accommodating 30 passengers.

An attractive alternative to the use of petrol burning heaters is the use of heat exchangers placed in the exhaust system. The risk of pollution of the ventilating air by exhaust gases can be virtually eliminated by the use of a secondary heat exchanger. With any such arrangement it is difficult to transfer the heat to the cabin interior, but relatively simple to add it to the air delivered by the blowers before this enters the fuselage.

To avoid the discomfort of sitting close to a cold wall but surrounded by a warm atmosphere, the heated air should be led behind the panelling or trim cloth before discharge into the cabin, thus turning the walls into low temperature radiant panels.

Humidity

The aircraft will be called upon to operate in widely varying conditions as the air at the normal operating altitude will contain little or no moisture while at ground level in the tropics, the relative humidity will commonly be very high concurrently with an air temperature of 100°F. At intermediate heights, although the relative humidity of the ambient air may be high and even reach saturation point, the moisture content of the air will often be small because of the low temperature, and when the air has been raised to the required temperature the relative humidity will have fallen to a figure so low as to be negligible. Unless some method is employed to raise the humidity, the only source of added moisture is the passengers, and if the ventilation rate is maintained at the stipulated figure of 1 lb. of air per minute per person, this source of moisture will be insufficient to raise the relative humidity above a very low figure.

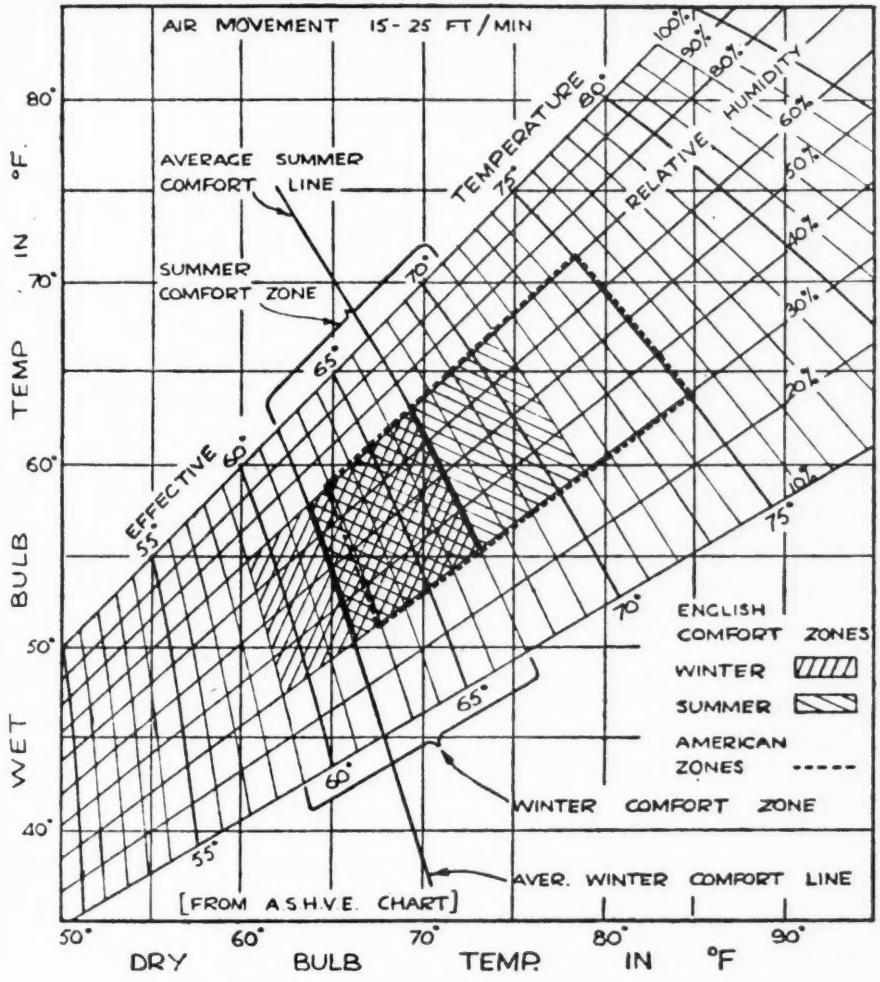

Fig. 4.

"Effective temperature" chart, showing winter and summer comfort-zones applicable to Great Britain only. The chart takes no account of radiation, and its use is limited to rooms, offices, homes and the like, where the occupants remain long enough to become accustomed to the conditions—say three hours' occupancy. The boundary of the corresponding zones recommended for use in the United States is shown by a dotted line.

The lower limit of relative humidity commonly accepted for buildings is 30 per cent. (Fig. 4) and this has been adopted tentatively for civil aircraft. Experience may show that it is possible to reduce this figure somewhat.

Further research is needed, but it seems not unreasonable to expect that alleviation of dryness of the throat and respiratory tracts should be associated with the total intake of water during respiration and not entirely with the drying effect of breathing dry air.

A point of importance, sometimes overlooked, is that the weight of water required to maintain a given relative humidity varies

inversely with the absolute pressure of the air (Fig. 5). A simple calculation shows that the water required for an aircraft with 30 occupants during a flight of 10 hours amounts to 78 lb. with 8,000 ft. conditions in the cabin, and 106 lb. with ground level pressure. (Cabin temperature 68°F. Relative humidity increased by 30 per cent.)

Thus while inspiring the requisite mass of air the occupants inspire the same mass of

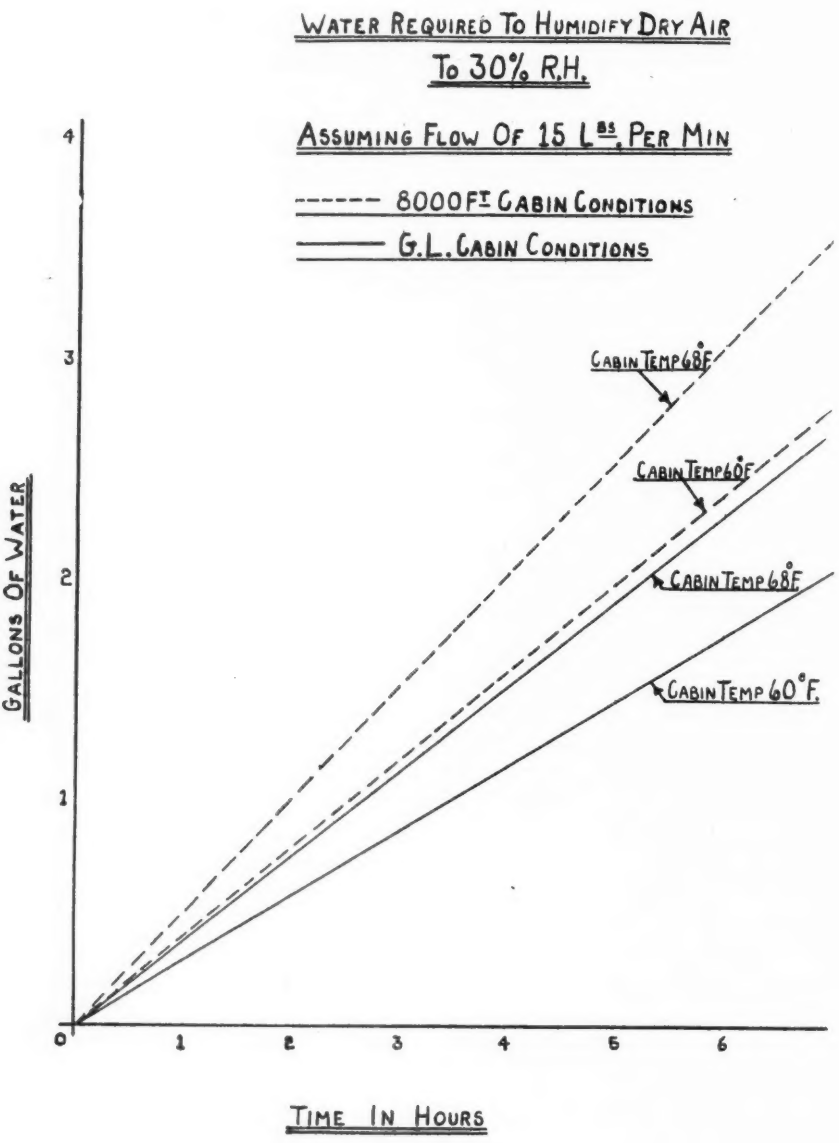

Fig. 5.

water with a lower relative humidity under 8,000 ft. conditions than under ground level conditions.

One of several methods may be adopted for adding moisture to the air to raise the humidity. Those commonly employed in buildings in which, *e.g.*, incoming air is passed through a chamber containing water sprays, is virtually ruled out by the size and weight of the conventional plants. Steam from from an evaporator or small boiler can be mixed conveniently with the incoming air. This method is simple and effective and has the advantage of providing easy control over the amount of added water by varying the rate of evaporation. This in turn is easily effected if the evaporator is electrically heated, as the control consists simply of an automatic switching arrangement to control the electrical input.

The evaporation of sufficient quantities of water employs a fairly heavy electrical load for example, to maintain a relative humidity of 30 per cent. in cabin with accommodation for 30 passengers at a temperature of 70°F. with incoming air at a temperature of minus 40°F. entails an electrical load of approximately 2.5 kilowatts per hour. Another possible disadvantage is the fundamental one, that with this system the addition of heat is inevitable. Water sprays of one form or another have been used with varying success, but great care is needed to ensure that the water is thoroughly vapourised and that droplets cannot find their way into the ventilating system.

Another attractive method, recently advocated in this country and now on trial, is to inject water into the blower where the mixing action in conjunction with the heat of compression may be relied upon to give very thorough evaporation and mixing. Great care must be exercised with this method to avoid freezing of the water in the pipe lines and as a safeguard against this eventuality, the present intention is that water shall be stored inside the cabin and that the pipe which delivers water to the blower shall be in close contact with the duct which delivers the warm compressed air from the blower to the cabin. Additionally, whenever the water supply is turned off the system shall permit a slight escape of warm cabin air by way of the same pipe, which is thus maintained dry and warm. The fundamental simplicity of this system is attractive, as the pressure within the cabin acting upon the water is sufficient to maintain delivery to the blower without the addition of pumps or the like. Trials already made have indicated that the injection of water into the blower has no effect upon its reliability or life. It has not yet been demonstrated that this system will be equally satisfactory with centrifugal blowers.

Drying

The conventional way of achieving this is, for example, by cooling the air before passing it through the water spray referred to under the heading of Humidification, to such a temperature that emerging saturated, when reheated to the required temperature it will be also at the desired humidity, but because of bulk and weight so far it has not been practicable to employ this method on aircraft. However, the fundamental method of cooling the air is still the best and convenient method when refrigeration is employed. In the absence of refrigeration a chemical drier may be used, such chemicals as activated alumina being employed to absorb the excess water vapour. A chemical drier could prove useful, especially when needed for short flights, but commonly excessive humidity is associated with high air temperatures and refrigeration appears to be the logical solution.

Air distribution

There is extensive literature on the subject of heating and ventilation of buildings which has been drawn upon freely, but the aircraft cabin presents a difficult problem, largely because of the small volume per person.

To obtain additional data an extensive investigation was made by the writer's organisation some two years ago, for which purpose a cylindrical test chamber was built, the

proportions of which represented closely a short section of a typical transport aircraft. This specimen was so constructed, and the ducting so arranged, that the distribution of the incoming air could be altered rapidly. Although it is not suggested that this is the only arrangement which would give satisfactory results it was concluded that the air delivered by the blowers was insufficient by itself, as the motion of the air within the cabin was so slow as to make it difficult to eliminate a sensation of stuffiness, or to distribute the heat satisfactorily.

This particular specimen represented only a short section of fuselage, hence on the actual aircraft there is the added difficulty of bringing about a full distribution from one end of a long cabin to the other and it is extremely doubtful whether, with the present meagre full-scale evidence, it is possible to design a system which will be correct in this respect. It is imperative, therefore, that prototypes should be so constructed that the distribution of air can be corrected during flight trials by the use of butterfly valves or baffles within the ducts, or at the outlets, as may be found expedient.

It has been objected that a re-circulating system distributes tobacco smoke and odours, whereas it would be better that they should be confined to particular sections. This is undoubtedly true and there is need of a good and effective air filter and purification system in the re-circulating system. This need has already been recognised both in the U.S.A. and this country, and steps are being taken to meet it.

Air which has once been admitted to sections of the aircraft where strong odours may arise, for example, kitchen, lavatories, and so on, should not be allowed to enter the re-circulating system, but should be discharged overboard. If such sections of the machine are widely dispersed, either extensive ducting must be installed or several discharge valves installed. The latter method has much to recommend it, as in most cases it will lead to economy of weight and ducting while eliminating the risks of leaks. The principle of employing multiple discharge points is now accepted and the necessary equipment is available. Care must be taken that the correct proportion of air is discharged at each point.

Air supply and blowers

It is customary to employ special blowers for pressurising the cabin, the only alternative being a tapping from the turbo-compressors where suitable power plants are employed.

The simplicity of the alternative is most attractive, but unfortunately the risk of contamination of the air has prevented its general adoption. This risk arises partly from possible surging of the engine, but more especially from exhaust gases or fluids should these be used for protection against ice.

The blowers at present in use in this country are of the Rootes type while the centrifugal type has been used in the U.S.A. to the exclusion of other types. Because of greater operating altitudes and cabin pressures the blower will be required to work at higher compression ratios, and in the near future a single stage will no longer suffice and multi-stage centrifugal types will be developed in this country.

It is customary to drive the blower from the engine and some control is necessary with either type to avoid an excessive delivery when flying low down and this may take various forms—

(*a*) Variable speed coupling, *e.g.*, electric hydraulic.
(*b*) Multi-stage gear box.
(*c*) Spillage of excess air.
(*d*) Throttling of the blower (centrifugal type only).

Hitherto system (*a*) has found favour in the U.S.A. while system (*c*) has been employed in this country.

There is much to commend the simple system of spillage but it suffers from the defect of being wasteful when the cabin air

is pressurised. On the other hand, it provides a definite safeguard against the delivery of contaminated air to the cabin in the event of blower becoming defective.

At present it is a duty of the flight crew to adjust the setting of the spill valve to ensure an approximately constant flow into the cabin, but steps are being taken to introduce an automatic device in the near future which will be suitable for employment with any of the systems.

TYPICAL LAYOUTS

The Avro Tudor I provides a typical installation (Figs. 6 and 7). Air entering through the filter passes to the engine-driven blower and thence by way of the silencer and heat exchanger to the cabin. Built in the cabin wall is a spill and non-return valve unit. This system is duplicated on each side of the aircraft and the incoming air is ducted to the re-circulating fan and heater, after which it is distributed throughout the aircraft. Before discharge into the cabin the air flows behind the trim cloth. The whole of the space below the floor is used as a return duct to carry air back to the re-circulating fan where it is mixed with the incoming fresh air from the blowers. It will be seen that air from the toilets and galley is discharged overboard.

The re-circulating fan is of axial type with two stages driven by an electric motor of .6 b.h.p. By employing two stages and a large diameter fan the noise level can be kept low. The discharge valve incorporates complete duplication inasmuch as the air is compelled to pass through two complete units arranged in cascade. This provides a safeguard against sudden deflation of the cabin in the event of partial failure.

The inlet filter is situated under the wing near the leading edge and is placed in this position so that the inertia separation can be relied upon to extract a high proportion of rain drops when flying in bad weather.

In the absence of refrigeration, the heat

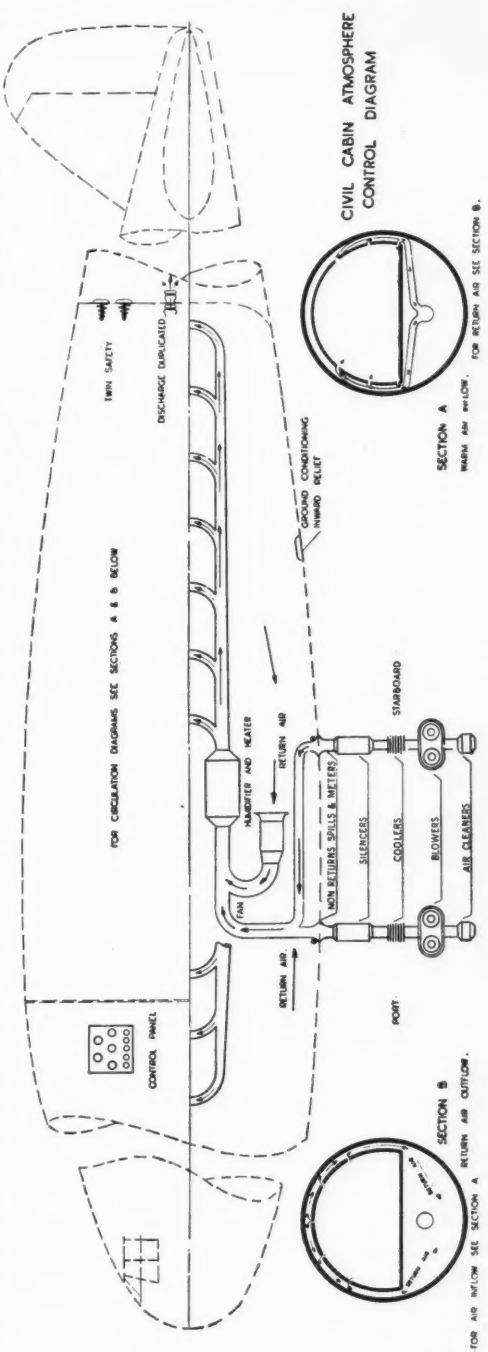

Fig. 6.

Fig. 7.

KEY.

A. Air cleaner
B. Cabin air blower
C. Silencer
D. Air cooler
E. Spill and non-return valve with flow indicator
F. Circulating fan
G. Heater
H. Heater auxiliaries and controls
J. Safety and ventilating valve
K. Discharge valve
L. Inwards relief and unpressurised ventilating scoop with ground truck connection
M. Control panel and master unit

exchanger must be as generous as possible as the temperature rise of the air passing through the blower is large, and even with the cabin operating at atmospheric pressure is far from negligible.

This leads to a large size but in the absence of refrigeration this appears to be well justified as the air in its passage through the blower and ducting may increase in temperature by as much as 15°F.

It will be noted that the silencer has been divided into two portions to damp out any resonance which might arise, one portion being situated near the blower and the other near the cabin.

The spill valve is of a simple type employing a sleeve to uncover ports in the duct, which is operated by an electric actuator controlled by the crew.

Another installation is shown in Figs. 8 and 9. This is, in fact, substantially the complete system employed on the Bristol Brabazon I. The principles employed are almost identical, but there are three discharge valves and three safety valves. There are two main reasons for employing three components instead of one large unit:—

(*a*) the internal arrangements are simplified by the avoidance of elaborate ducting to carry the discharged air to a common valve.

(*b*) the employment of standardised units is made possible.

It will be noticed that three heaters are used instead of one, and that the temperature of the air supplied to the three main compartments is separately controllable. It is highly probable that the air supply to, for instance, the bar should be at a slightly lower temperature than that for the main cabins.

REFRIGERATION

The necessity for refrigeration was for long the subject of controversy, but now there is almost general agreement that it is a necessity, at least on a high proportion of air routes.

Refrigeration machinery of sufficient capacity also provides the solution to the problem of reducing excessive humidity.

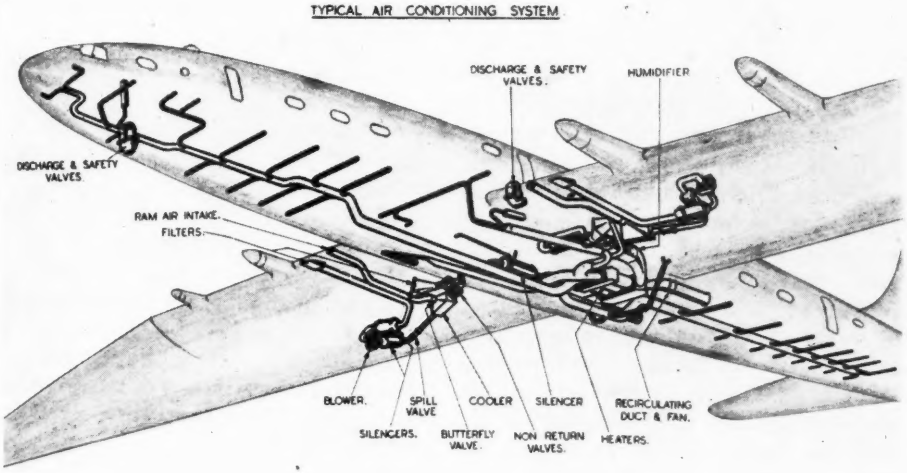

Fig. 8.

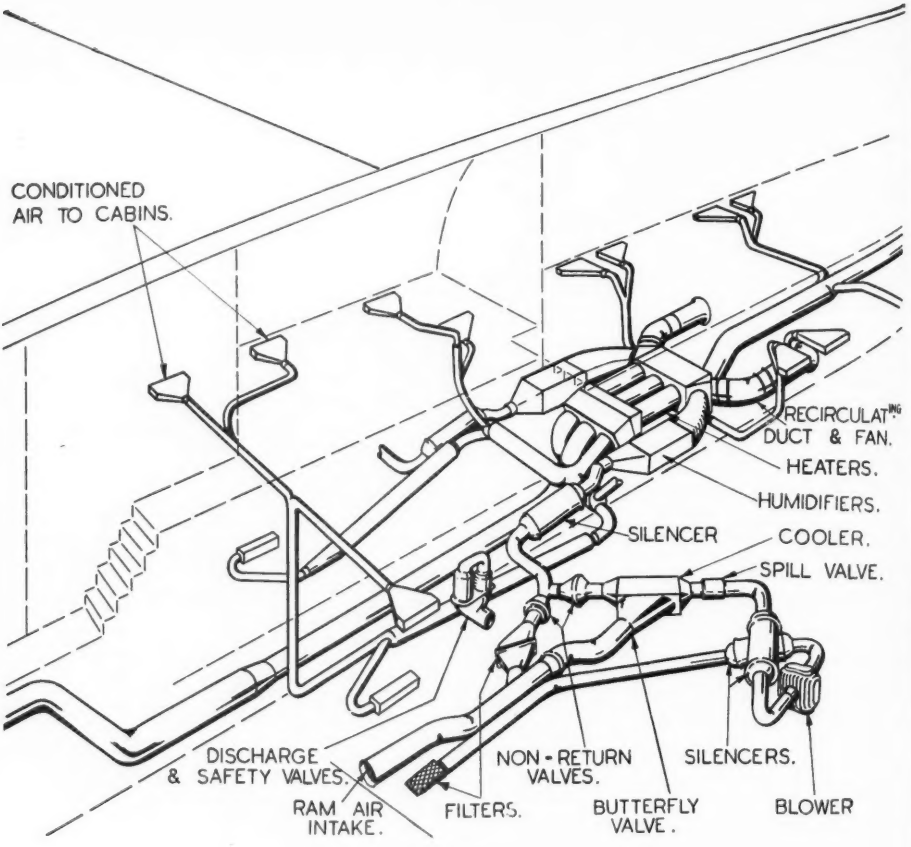

Fig. 9.
Typical air-conditioning system.

Instead of refrigeration the installations already described include a generous retractable air scoop for use at low altitude in regions where high temperatures are encountered. This ensures a generous supply of fresh air which has not suffered the heating effect of passage through blowers and ducting.

Conditioning of the aircraft while on the ground is done by suitable ground trucks, but great discomfort from heat may arise during a protracted take-off or when flying low down for any considerable period.

Broadly speaking there are two ways in which cooling of the air and the cabin may be affected.

(*a*) refrigeration machinery may be installed on the aircraft.

(*b*) a supply of ice or solid CO_2 may be loaded into the aircraft and used to cool the cabin.

The latter method is simple and attractive, but has the disadvantage that the cooling effect can be maintained for very short periods only unless a quite unreasonable weight is carried.

Refrigeration machinery will work continuously and has the great advantage that

the aircraft is not dependent upon a supply of ice or CO_2 at the various ports of call.

It has been argued frequently that in a well-organised airport the period of time occupied for take-off will be small and this, in conjunction with the rapid rates of climb envisaged with the latest types of aircraft, makes the storage method appear suitable as refrigeration is obviously not required when the aircraft is flying on its course at the greater altitudes.

A more real difficulty is that associated with difficult landing conditions when the aircraft may be compelled to spend some time at low altitude while awaiting instructions to land.

Some system by which water might be re-frozen while in flight can be envisaged, thus ensuring a supply for descent, but the only satisfactory solution appears to be the employment of machinery, and this is divisable into two main categories:—

(1) Refrigeration machinery of the conventional type using a compressor and expander and some such gas as Freon.

(2) The type now commonly employed which uses the compressed ventilating air as a working fluid. This system, which is fundamentally simple, produces the desired effect by compressing the ventilating air to a pressure greater than that required and then passing it through an expander, a cooler being interposed between the compressor and the expander.

Fortunately, the characteristics of the blowers at present in use lend themselves to this procedure as they readily produce a high pressure near the ground and the fact that the high pressures cannot readily be developed at greater altitudes is of no significance, because the refrigeration effect is no longer required.

Each of these systems has advantages and disadvantages. The Freon system is well tried, reliable and the cycle employed gives a high efficiency. The simple system employing an aircraft compressor in conjunction with an expander is light and simple but operates at a lower efficiency. The expander turbine runs at a high rotational speed and this naturally calls for careful design and development. Some way of employing or dissipating the power developed by the expander turbine must be devised, for example, it may be seared to the main compressor so that its power is fed back into the system or, alternatively, the power may be used to drive a booster compressor or to force a flow of air through the inter-cooler. It is impossible to recommend either one or other of these arrangements without due regard to the requirements of the aircraft. For example, if the refrigeration system is to work when the aircraft is stationary with the engine stopped, then it may be vital to employ some of the power to ensure a flow of air through the cooler.

WEIGHTS

Considerable difficulty attends any attempt to make an accurate statement of the additional weight attributable to pressurising in aircraft, as to do so we must assume that an aeroplane can be built either with, or without, at will. Although this may be true for some aircraft as oxygen for crew and passengers can be fitted to some of the interim types now flying, it will manifestly become impossible to do so in the near future. Modern fuselage construction and shapes lend themselves to pressurisation and a great proportion of any additional weight is employed to effect sealing and to carry out local stiffening. Attempts at an assessment have been made from the limited experience of British constructors, and it seems fair to assume that the structure weight of the fuselage should not be increased more than 5 per cent. on this account. Experience of complete installations is still limited, but the actual weight of the complete installation on the Tudor I amounts to approximately 770 lb. An important point not to be overlooked is the economy of weight

effected by the elimination of oxygen gear which, with sufficient oxygen carried in cylinders for a flight of 3,000 miles with 20 passengers could not be much less than 1,000 lb.

With regard to the statement that it is difficult to get overall figures with any real significance, it must be borne in mind that much of the weight involved in providing comfort for passengers on the scale now considered necessary for long distance passenger flights, will be incurred on non-pressurised aircraft equally with pressurised. For example, of the total additional weight of 770 lb. on the Tudor I some 200 lb. is attributable to ducting, heating and so on which is indispensable, apart from pressurising. It is fair to say, therefore, that there is an economy of nearly 500 lb. because of the use of pressure instead of carrying full oxygen and equipment which leaves a margin, even after making allowance for the additional petrol which must be carried to provide the power for the blowers.

FUTURE DEVELOPMENT

It will have become apparent that hitherto there has been a sharp line of demarcation between the simple installations in a pressurised fighter and the much more comprehensive installation in a civil transport aeroplane, but the trend in future is certain to be markedly different. The experience and the lessons learned in operation of the newer civil types are already being applied when considering military types. From the operational point of view, moreover, the requirements of military and civil machines are converging rapidly.

It is well known that in the near future we may expect to see civil transport aircraft flying regularly at heights up to 50,000 ft. and at this height a sudden loss of pressure caused by either accident or enemy action is likely to be accompanied by fatalities. This is particularly so in civil aircraft where all types of unselected passengers are carried at will, these including the very young, the aged and the infirm. In fact, in the new projected aircraft a cabin failure will be just as disastrous as a main structural failure and hence every possible precaution must be taken to avoid such an occurrence. This might mean, among other things, that full duplication will be called for on all military types. Similarly, when considering comfort there seems no legitimate reason why experience and knowledge gained on the civil types should not be used to give greater comfort to the crews of service aircraft.

It should always be borne in mind that greater comfort means improved efficiency of personnel, which has obvious military advantages. For instance, arrangements for humidifying the crews compartment of a bomber by lessening physical fatigue and preventing irritation of the eyes might be very valuable. However, here the writer is encroaching on the sphere of the physiologist and can only express an opinion. Naturally, there will be differences in practice, for example, the crew of a military aircraft would scarcely be allowed to go into action with full pressure; on the contrary, they would probably be instructed to reduce pressure and use oxygen so that the sudden effect caused by loss of pressure through enemy action would be minimised. In such an event considerable care must be exercised with respect to humidification, as a sudden reduction of pressure with humid air would lead to sudden misting and leave the crew temporarily blind. Thus we may expect that reduction of pressure to a combat value might be accompanied by a controlled reduction of humidity to prevent such an occurrence.

The writer is not in a position to dogmatise on such questions and can only point out probable lines of development. The provision of 1 lb. of fresh air per minute per occupant means that a considerable horse power is being expended continuously in pumping air into the fuselage, and at present none of this power is recovered. Development might

possibly result in a reduction of the supply of fresh air in conjunction with an effective air purification plant or, alternatively, equipment may be developed which will recover the power expended in initially compressing the air.

We have a serious problem in humidification which at present necessitates the carrying of a considerable weight of water which is a function of the quantity of fresh air pumped into the fuselage and is not seriously affected by the number of occupants and, if it proves possible to reduce the amount of fresh air supplied, it follows that the amount of water required is automatically reduced. Alternatively water recovery plants may be developed which will extract water either from the air discharged from the cabins, or from the engine exhaust.

As regards the general layout of the system, the engineer is at all times compelled to work with the apparatus available; nevertheless, the writer feels that the present methods by which temperature control of the cabin is effected by raising or lowering the temperature of the fresh air supplied by the blowers, might well be a passing phase and that further development may lead to a design in which control of the cabin atmosphere is effected by conditioning equipment carried within the aircraft, and the blowers will be used purely to supply the necessary amount of make-up or fresh air. If such a desirable state of affairs can be brought about we should be in a position to dispense with the elaborate ground trucks which at present are necessary for supplying conditioned air when the aircraft is on the ground. It appears regrettable that elaborate apparatus should be carried which is needed most when the aircraft is near the ground, if such apparatus is not available when the aircraft is stationary.

This problem is already being attacked from several angles; one obvious solution is the provision of an auxiliary engine, another is by use of electrically driven refrigerators and so forth, while yet a third can be provided by having apparatus which takes its power from a compressed air supply.

There is some reason to believe that pressurisation will be demanded by operators for purely economic reasons, as the ability given to crews to make rapid climbs and descents will result in a saving of flight times that will more than compensate for the cost involved in carrying and servicing the equipment.

DISCUSSION

N. E. Rowe (F.R.Ae.S., Vice-President): He was glad that Mr. Widgery had tried to break away from the rather dreadful word "pressurisation." It conveyed a great deal, but not nearly enough of what was wanted in cabin air control; it was obvious from the paper that they were aiming at complete air conditioning. If at all heights a cabin pressure equal to the atmospheric pressure at ground level could be achieved, so much the better. Could Mr. Widgery indicate the relative economy of doing that, especially at great heights? In one of the slides the difference between ground level pressure and the pressure at 8,000 ft. was shown as about 4 lb. per sq. in., and the pressure that had to be applied to reach sea level cabin conditions instead of 8,000 ft. conditions, was proportionately less at greater heights. Therefore, the higher an aircraft flew, the less trouble there might be in achieving ground level pressure instead of 8,000 ft. cabin conditions.

The whole subject was of great importance in relation to the use of turbine propulsion, either with the propeller or with the pure jet; aircraft so propelled were forced to fly high if economy were to be achieved. Rather than limit considerations to individual details, pressurisation should be regarded in the broader sense that it was essential for the future, and engineering skill should be

applied to the apparatus as a whole to reduce the weight as much as possible.

A complete loss of pressure when flying at great heights, such as 35,000 and 45,000 ft., and even more, would be disastrous in a civil aircraft; it must not happen. Thus there must be a long period of development ahead to ensure that the cabins themselves, the partitions, the windows, the means by which the required pressure was achieved and maintained, and so on, were so tested and tried that they were absolutely certain that when the aircraft was in the air there would not be such a failure as would give rise to a sudden loss of pressure. That was his own view and he would like to hear the views of others.

The advantage of being able to change altitude readily in the air was very real in civil aviation, and as more was understood about pressure patterns over the wide areas of the world it would be even more necessary from the standpoint of economy to be able to do that; thus cabin air control offered further opportunities for economy.

When referring to comfort, Mr. Widgery seemed almost to regard it as incidental; he seemed to refer to cabin air control as something which, of course, had to be provided for comfort, as though comfort were not a proper and necessary condition. Only that day, he had been talking to a young and intelligent man who had said that he did not fly nowadays if he could avoid it, because it was so uncomfortable! Flying must be made more comfortable.

Would Mr. Widgery give his views as to how the difficulties of dealing with the noise problem would vary with height, bearing in mind that, as heights increased, much more power must be put into the blowers in order to obtain the pressure differential desired, so that the noise problem would become much greater?

He was attracted by the suggested development of re-circulation so that all that was needed from the fresh air was a make-up feed, as it were, so that much less pumping would be necessary.

Again, the problem of air purification arose in that connection; and if the air were not purified when re-circulated, the practice of air re-circulation would not be popular. Doubtless, in the course of the developments in mind, the demand for purification would become insistent, since re-circulation offered such advantages in operating economy. He would be interested to know when results could be expected, and what were the difficulties, which, he suspected, would be considerable.

Had Mr. Widgery any general views on the economic limits in terms of height. For example, it might pay to operate even a turbine at 40,000 rather than 50,000 ft., if thereby they could avoid the greater complexities which would be involved in pressurisation at greater heights.

There had been no reference in the paper to ducting and ducting losses and how they might affect the balance of heat; that might arise especially, perhaps, in refrigeration. Little had been done in that direction, but the problem had to be tackled. Looking at Mr. Widgery's diagrams and thinking of the aircraft installations, he had been impressed by the probable complexity of the ducting systems—the number of separate lengths, the bends and the general effect on the whole process of air circulation, which in turn might affect in a critical way such matters as refrigeration and the general heat balance. He would be glad to hear something from Mr. Widgery in that connection.

Contributed.

He had an impression of over-complexity. There were coolers and heaters, silencers and controls of all sorts, many of them, he suspected, automatic or semi-automatic. All those things would have their own troubles in service and might give rise to excessive time spent in maintenance. Having got the system to work, they should now make a most energetic attack on its simplification.

He was not clear what precautions were being taken to prevent the icing of the safety valves to which the lecturer referred, and would be glad of information on that point.

S. Scott Hall (F.R.Ae.S., Ministry of Supply): He agreed with Mr. Rowe that they were really aiming at complete air conditioning in aircraft cabins. His own experience of pressurised flight was extremely limited, and on the flight in which he did experience it, in a type of British aircraft which was much in the public eye at the moment, everything had worked extremely well; beyond a slight feeling of dryness in the throat, he could not criticise in any way the conditions in the passenger compartment of that aeroplane. Perhaps there were some present at the meeting who could give a more vivid picture of the discomforts which aircraft passengers might have to suffer in the course of travelling to different parts of the world both under artificial pressure and without. In order to afford a complete study of the subject it would be extremely valuable to have data, which probably existed, on the humidities, temperatures, and so on, which would be experienced in air liners flying over the more important routes, and their relation to comfort.

He confessed to a considerable degree of ignorance concerning the physics of the subject, which he had found difficult to understand, and about which he would be glad to hear more.

In Mr. Widgery's diagram of comfort conditions, the American zone of comfort was larger than the British, and that had puzzled him. Were the Americans a tougher race, or was it because temperature conditions in America in summer were higher up the scale than theirs in Great Britain?

He challenged Mr. Widgery's remark that the military and civil aircraft requirements were converging rapidly; he would have thought that military conditions would always have to be more severe, on grounds of weight conservancy, and vulnerability, than civil.

Safety in pressurisation schemes for civil aircraft was absolutely vital. There had been experience of one or two failures of pressurisation schemes on the world's airlines; he believed that, fortunately, those failures had nearly all been without fatal consequences, although in some the people who were travelling had been very lucky. They could not afford to risk any failures caused by the breakage of windows, for example, at the heights at which they hoped to fly.

He would like more information about the air purification scheme mentioned by Mr. Widgery and also, if possible, some idea of the cost and weight involved in the adoption of such a scheme as against the direct use of fresh air.

He would like to hear more about testing. Difficult problems had already arisen in connection with vibration and noise—and he would like to know what ideas Mr. Widgery had on the complete ground testing of such systems to ensure that delays would be avoided after installation in an aeroplane.

R. Graham (F.R.Ae.S., Royal Aircraft Establishment): Within the past month he had made a trip to Montreal for the purpose of experiencing flight in a pressurised Constellation. After taking off from Heath Row, the pilot of the aircraft had come along to say he had been warned that Mr. Graham would be a passenger, but that he was sorry that the pressurisation had been disconnected! The pilot had not told him before taking off, lest he might think that he ought not to make the trip! Thus, he had had the experience of flying in a Constellation unpressurised; and in certain respects it was unpleasant. He considered that long-distance flying was one of the most boring forms of travel; therefore, every effort must be made to raise the standard of comfort to a very high level so that in that respect it would be superior to other forms of travel.

In order to fly in a pressurised aeroplane he had had to go to New York and then to

Miami and had flown in a Constellation in which there was not only pressurisation, but refrigeration. When the pressurisation system was started it was set for a rate of climb of 300 ft. per minute. Instead of that the altimeter began to whirl around in both directions—not both at the same time—the rates of climb and descent being about 10 times as much as they should have been. Under such circumstances the facilities which were provided to improve comfort could cause more discomfort than would be experienced if they were not provided.

His experience there was useful. The aeroplane was not quiet; indeed, he had not yet flown in any aeroplane which was. But he did feel that the noise from the pressurising equipment was masked by the much greater noise from the engines. When engine silencing was improved—and he believed there was some hope of turbine-driven propellers being quieter than anything they had so far—improvements in ventilation silencing would be necessary. On the Constellation, when the engines were shut down, the air could be heard hissing through the ventilators quite noisily.

P. G. Masefield (F.R.Ae.S., Director-General Long-term Planning and Projects, Ministry of Civil Aviation): He believed all were agreed that pressurisation was probably one of the three great problems of civil aviation to-day. Pressurisation could be divided into two classes—"medium" and "rare." The "medium" was that with which they were becoming familiar—in spite of Mr. Graham's unfortunate experience—pressurisation for heights up to about 25,000 ft.; the "rare" was the pressurisation they would have to produce within a short time, for heights of 40,000 ft. and higher, which he believed was one of the factors on which the success or failure of some of their new civil aircraft would depend.

All their experience so far had been with the "medium" type of pressurisation, and a great deal of success had been achieved. It was interesting to know that, as Mr. Widgery had said, a large proportion of operators to-day were asking for pressurisation, not only for flying at great heights, but even for flying at heights up to 10,000 ft. He had found in Australia that nearly all the Australian airlines were going to ask in the future for pressurisation in aircraft which normally would not cruise at a height of more than 10,000 ft. The reason was that in, for instance, icing conditions, it was necessary to climb quickly over the top of the icing layer, without subjecting passengers to uncomfortable conditions.

There was, he suggested, a trinity—of pressure, temperature and humidity. Cabin pressure, if possible, should be ground pressure, and temperature should vary ideally with the relative humidity. He had had the fortune to fly for about 100 hours altogether in pressurised aircraft in various parts of the world, and had carried with him a humidity indicator, an altimeter and a thermometer. He had noted that different temperatures affected one differently according to the humidity of the air in the cabin. In one Constellation flying across America—not the "Gold Plate" variety—the humidity had gone down to about 3 per cent., although the temperature was 90°. On another occasion, when flying from Australia in a Lancastrian, the temperature was only 70°, but the humidity was up to 90 per cent.; and everyone was pouring with perspiration.

Refrigeration would be important when coming into warm aerodromes, and particularly in a pressurised cabin where at present there was not always the circulation rate that would be developed later.

Some of the new aircraft would stand or fall, economically at any rate, by their pressure systems. Would Mr. Widgery give his views concerning the permissible rate of leak from places such as cabin doors and other openings, which must be provided, and

what could be done to reduce pressure leaks when they came to the very high pressure differentials?

Recently a Constellation had descended very rapidly from about 20,000 ft. to ground level in order to get through ice quickly. The internal cabin pressure was still equivalent to that at 8,000 ft. when the machine had reached ground level. On that occasion a door had blown in. Thus, it was important that the doors should be strong both ways.

When in the longer term future they were flying really high, at, say, 250,000 ft., they would not be able to suck air into the aircraft at all, and might have to adopt the submarine method of air conditioning—carrying the air in the aircraft. They need not worry about that just yet, but perhaps they would have to do so not very many years hence.

He had come across one experience of what happened in certain instances when bleeding air from the compressor of a jet engine. It was in connection with the early American bids for the speed record last year. In the early stages of the preparations they had tried alcohol injection into the engines to increase the boost. On the initial ground runs the alcohol was injected, and the pilot eventually came from the cockpit singing ribald songs and walking on all fours, having inhaled a lot of alcohol. If similar results were obtained on commercial aircraft, he was not sure whether it would tend to increase passenger bookings—or the reverse.

J. G. Willis (Project Designer, A. V. Roe and Co. Ltd.) paid tribute on behalf of his Company to the Westland Company for the excellence of the equipment which had been supplied for the Tudor, and said that the only complaint from one operator was regarding the manual operation of the flow valves; there was no doubt that this must be made automatic.

Most of the complication of ducting was probably due to installing it last and arranging it to clear secondary structure, such as floor support members and such like. In future, therefore, they must lay out the piping first and put down some of the secondary structure afterwards.

Other leakage troubles which had been experienced had been at cockpit windscreens and at some of the secondary entries to the pressure cabin, such as controls, aerials, and so on. Most of the problems that had arisen could be solved by straightforward engineering technique.

Dr. H. Roxbee Cox: As well as purifying the air they must attempt to purify the language applied. For example, he did not think the word "de-humidification" was really necessary; would Mr. Widgery explain the difference between that and "drying"?

He hoped Mr. Saunders or other experts would write a comment about the bleeding of air from the engines, because it must have unfortunate effects on the power of the engines at high altitudes and at high speed when the ratio between that which was bled and that which was going through seemed to be too large for the comfort of the engine.

H. Saunders (Gloster Aircraft Co. Ltd.) *contributed*: (1) Attention was drawn to the statement that in the case of such aircraft as the Meteor, in which cabin pressure air supply was obtained by tapping one of the gas turbine compressors, there was risk of cockpit contamination. This was a scare which had arisen on occasions, usually as the result of a pilot reporting a smell in the cockpit, but it had invariably been found that such smells had been due to spilt fuel, oil or hydraulic fluid, or running engines on the ground with the aircraft tail to wind. Flight tests made by Rolls-Royce Ltd. and Gloster Aircraft, which had included tests in which engines had deliberately been held in a surging condition, had quite definitely established that no cockpit contamination occurred. He would also point out that the Meteor cockpit was supplied by air from both engines, first from the safety point

of view, and second to make possible pressurised single-engined cruising.

With reference to effect on engine performance, in the case of the Meteor the quantity of air used for cockpit heating and pressurising purposes was 3 lb./min. at sea level, reducing to 1½ lb./min. at 40,000 ft. These values, which represented less than 0.1 per cent. of the mass flow through the engine under cruising conditions at sea level and approximately 0.15 per cent. cruising at 40,000 ft. had been found to have an immeasurable effect on the performance of the Derwent V engines used. In fact, engine tests had been made in which ten times the amount of air had been tapped from the compressor, effects on fuel consumption, thrust, and jet pipe temperature having been found to be negligible.

The problem of ensuring adequate pressure at low r.p.m. at altitude became a consideration, but the same problem presumably arose with auxiliary blowers, the immediately important matter being to ensure a low rate of leak from the cockpit in relation to loss of height of the aircraft at low engine r.p.m. values.

The foregoing remarks were not intended to be in any way general, it being fully appreciated that this system precluded the use of certain de-icing methods, and that it would be unsatisfactory in the majority of other engine and airframe combinations for a variety of reasons.

(2) Flights to 45,000 ft. in fighter aircraft were now commonplace, their experience having confirmed the view of the Institute of Aviation Medicine that this altitude was the maximum at which it was reasonably possible for a fit pilot to retain sufficient control to make a normal descent, should the cabin for any reason become de-pressurised.

Since standard Service aircraft could already be flown to greater heights, it became of extreme importance that the design of pressure cabin equipment must be such that accidental failure was virtually impossible, particularly in the case of single-engined aircraft. Further, since pressure might be lost through quite minor effects of enemy action, a form of emergency pressurisation should be available.

It was unfortunate that few people had had actual experience of flight at such altitudes and therefore that the necessity for such a safeguard as the pressure suit was not accepted sufficiently widely to ensure the availability of adequate development resources.

One of the fundamental reasons for slowness in development of aircraft of all types was that design or material weaknesses did not become evident until intensive flying, covering the complete range of limitations of the type, had been done. This was generally accepted and as much time as possible was saved by tests of all kinds before the aircraft flew, but, with particular reference to fighter aircraft, one of the immediate problems in ensuring pressure cabin reliability arose out of the high rates of climb and descent which were becoming possible, and he felt that if ground test facilities existed in which still higher rates of climb and descent could be fairly faithfully simulated, in respect of altitude, temperature, airspeed and humidity, a great deal of development time could be saved.

(3) The problem of temperature control would seem likely to become of considerable importance in the near future. The difficulty of keeping a pilot cool under high speed, high ambient temperature and low altitude conditions, and warm under slow cruising and high altitude conditions, was becoming increasingly serious.

A. W. J. Smith (A.R.Ae.S.) *contributed*:

(1) There was no provision for humidification on the Tudor. Assuming that the aircraft was operated at 20,000 to 25,000 ft. for 8 to 10 hours, under 8,000 ft. cabin pressure conditions across a route on, or near, the equator

were the occupants liable to suffer sore throats, would they have to drink fair quantities to prevent this condition and for how long under these conditions could they fly and feel no discomfort—"dry" or "wet" (with or without drinks)?

(2) With a humidifier incorporated, how many gallons of water would be needed for 8 hours' pressurised flight at 20,000 to 25,000 ft. in a Tudor IV, 32-seater?

(3) What happened to the water vapour; did it accumulate under the cabin floor, for instance, between formers and stringers, or cause any other troubles?

(4) The Marshall-built, Rootes-type blowers took some 35 b.h.p. each to drive, if he remembered correctly. Those were direct-drive from Rotol gearboxes, and were always absorbing this power. Mexico City airfield was 7,000 ft. above sea level, and on a day when "temperature accountability" was not being very kind to their aircraft, that two to four per cent. of output of *both* outer engines would be very useful. In fact, at many airfields he had used, it would be *critical* on a bad day.

Why could they not have a simple clutch, manually or electrically-selected from the Westland panel, on the lines of the Merlin supercharger clutches or a Borg and Becke single plate? It could be quite a simple addition, and he thought 70 b.h.p. at the cost of, perhaps, 5 lb. extra weight was not a bad bargain!

(5) Could Mr. Widgery give some details of the layouts of the Constellation and D.C.-6 pressurisation schemes?

The D.C.-6 appeared to be almost completely automatic in operation from take-off to landing. Was this caused by a restricted available altitude range or control system? Could certain altitudes be selected, as on a Westland system?

Could the Westland controls be made "interlocking" in action? So that, for example, the extractors could not suddenly be pushed wide open, with discomforting results, when the aircraft was at 25,000 ft., 8,000 ft. cabin conditions, or prevent pressurising too fast *at all*. He realised that this was a big problem, but surely it was a line of obvious development?

F. Radcliffe (F.R.Ae.S., Handley Page Ltd.) *contributed*: The foundation for pressurisation had been well and truly laid and they could say that they were now concerned with refinements. Some of the current problems that faced the airframe designer were grouped under the following headings:

Structural. Windscreens, astrodomes, doors and windows provided items for further study. In particular, the properties of glazing materials gave rise to anxiety on account of their tendency to crack under load at low ambient temperatures. It seemed likely that only by rigorous inspection of glazing panels for incipient cracks and scratches could they hope to eliminate much of this trouble, but, at the same time, any further technical information that could be collected would be extremely valuable, *e.g.* how best to mount such panels. Seals for doors and hatches could be made with inflatable tubes or with simple sheets of rubber which came into action by utilising the differential pressure across the door surround. Extensive testing would reveal which was the better scheme.

To provide minimum aerodynamic drag, flush-riveted fuselages were desirable, but, to date, except with thick plating, there had not been great success in making leak-proof joints. Further development work was thus indicated.

Blowers, control valves, controls, and so on. The trend towards flying at still higher altitudes had emphasised the need for centrifugal-type cabin blowers with variable speed drives in place of the current Rootes-type blower. While the displacement blower was reliable and trouble-free, it was undoubtedly noisy and required effective silencers. Centrifugal blowers had not required silencers so

far. It was a matter of some concern to the power plant designer when centrifugal blowers were proposed, on account of their bulkiness and a certain amount of unreliability in the drive which had been experienced on some American aircraft. Careful development work followed by testing would provide them with reliable centrifugal blowers in due course.

Heaters. They had not made up their minds as to the best manner of obtaining heat for use in the passenger cabin and it appeared to him, at any rate, that every case would have to be judged on its merits. If they included the heat to be supplied for de-icing wings and tail, they saw at once that heat from a combustion heater was by far the best scheme for de-icing the tail unit, but the answer was open when they considered heat for the cabin and wing de-icing. If space permitted, exhaust-gas heat exchangers were convenient but there were many cases where a strong preference could be shown for combustion heaters, especially as they could be fitted to be dragless when not in operation. It was as yet too soon to say what would be the concensus of opinion when jets and propeller-jet units were installed. The presence of quantities of hot gases would naturally attract one to try to exploit it as a source of heat.

Air Conditioning. It was probably correct to say that their most difficult problems were those connected with the air conditioning of the aircraft both on the ground and in the air. This brought in train—thermostatic controls, humidity control of the cabin air and refrigeration — all intimately linked together.

Commercial air conditioning practice had provided the aircraft designer with a valuable background of information, but the specialised requirements of aircraft air conditioning were entirely different when flight at altitudes under world-wide conditions had to be met. Basic data were required for determining both the technical requirements to be met and the characteristics of the airframe itself as a body to be heated or cooled. Detailed information was needed of the temperature, humidity, and the effects of the sun's radiation in all parts of the world and more precise information on the characteristics of the air at altitude—all referred to frequency of occurrence.

From the airline operators, the designer would like to see issued, as soon as practicable, detailed information on the standard procedure for taking-off and landing aircraft on scheduled aerodromes. This information would cover such items as, the time allowed for cooling down or warming up an aircraft prior to beginning its daily duties, the time allowed for standing by during loading or unloading operations, and the maximum time allowed for taxying and queueing. This information would supply part of the data for determining how much refrigeration or heating had to be supplied. The remainder had to be obtained from practical tests made on existing aircraft for establishing how much heat was required to heat up or cool down a specific aircraft. All this was new information which was required by the industry to enable it to design efficient equipment.

The control of the humidity of the cabin air in relation to temperature required, as Mr. Widgery had stated, a better understanding by all. With modern high speeds, the changes of climate could be wide and unless there were means of mitigating the extremes, the attractiveness of air travel would be substantially offset. He supported complete "cabin air control." He had had the privilege recently of first-hand experience of pressurised and non-pressurised aircraft, and it was soon abundantly clear how superior was flight in a pressurised aircraft. The effects were noticed also on fellow passengers, especially during landing. The pressurised cabin seemed a powerful factor in preventing sickness and was generally responsible for causing less fatigue.

Long journeys caused a dryness of the throat with a pronounced tendency to yawning. Control of the humidity in the cabin would remove this unpleasant feature, but as the lecturer had shown, only at the expense of water carried in the aircraft. The designer would be glad to have more practical data on the points to be met when humidification was achieved by metering water into the Marshall-type blower. The reverse process, namely extracting moisture from the air, required further development.

From experience to date it would appear that civil aircraft would have to be cooled down initially by means of ground equipment and that all that could be expected of airborne equipment would be the maintenance of a slowly rising temperature after the aircraft was taken on the aerodrome and separated from the ground truck. For certain temperatures a balance would be held, but at higher temperatures, the cabin temperature would perforce rise. Operational experience was urgently required to assist the aircraft designer in these problems.

Testing Equipment. What was impressive about this relatively new subject of cabin air control was the necessity for providing trouble-free equipment. This, in turn, meant extensive testing and the recent installation of large low-pressure chambers indicated the higher costs involved in fitting such systems in aircraft. The fact that fare-paying passengers were to be carried in pressurised aircraft compelled one to ensure their safe travel by all the means at their disposal and this, as had been noted, was involving considerable additional charges for pressurised aircraft.

F. Pye (A.F.R.Ae.S.) *contributed*: He had hoped that Mr. Widgery would have dealt with cabin blowers and refrigerators in much greater detail as, apart from the definite cleavage of opinion between Britain and U.S.A. on the use of Rootes-type blowers, the blower was likely in future to be the sole source of the conditioned air that reached the cabin—in itself contributing to the conditioning by humidifying as required. In Britain the design and development of Rootes blowers for civil aircraft followed on naturally from experience with this type during the war, but it was also proved later to be the correct approach for civil aircraft, as the inherent flexibility of the Rootes enabled changes during the development of prototype aircraft to be made without the necessity for a corresponding change in the blower design. The demand for larger outputs together with the higher operating altitude of turbine propeller installations was now leading to a change-over to centrifugal types, largely due, he believed, to the weight and bulk of a multi-stage Rootes-type.

The change-over from Rootes to centrifugals only appeared justified when outputs in excess of 70 lb. per min. at medium and high altitudes were required and he could see no logical reason for introducing the complication of centrifugal blowers to any military applications, both present and future. The explosive de-compression factor mentioned by Mr. Widgery was not only of concern to the pilot. If centrifugal blowers with their clearly defined operational characteristics were fitted, destructive mechanical effects from blower drives and controls might arise that affected main engine reliability. Hence for military aircraft there seemed good reasons for designing pressurisation equipment in its simplest possible form and only using apparatus that had a large functional tolerance in service.

In the past excessive vibration and noise had been alleged against Rootes designs but there was no evidence to suggest that the higher frequencies of the centrifugal blower would be any less troublesome and with existing Rootes-types the adverse effects of vibration upon ancillary equipment had now been overcome. The noise aspect was also being dealt with by various specialist bodies but for all practical purposes it had not prevented normal conversation in those

installations now flying, provided that precautions in fitting suitable silencers were observed. His own experience would suggest that the noise levels recorded from Rootes blowers running in a confined space, such as test shop or flight shed, were exaggerated by these surroundings and in flight the noise appeared to be effectively damped out before reaching the cabin.

The design problems of a centrifugal cabin supercharger system of air conditioning were by no means simple and they introduced a new conception of automaticity of operation and control which had never been envisaged before. Without going into too much detail the design of an automatic four-speed gearbox with the provision of a suitable delay device to avoid hunting at critical altitudes, the matching of a number of centrifugal blowers fed into a common receiver, the automatic operation of mass flow control valves, the provision of instantaneous temperature correction devices at gear change periods, automatic oil cooler and humidification equipment operation, all called for specialisation of design to a marked degree. He thought Mr. Widgery had tended to oversimplify the advent of centrifugal cabin superchargers in their application to high altitude civil aircraft of the future.

Refrigeration requirements had recently been clarified and the more precise figure of 5°F. C.E.T. difference had been stipulated, retaining, however, the old limitation of not more than 10°F. dry bulb temperature difference to avoid shock when leaving or entering the aircraft.

Current developments relied on the air cycle in the form of a free running compressor/expander mounted on a common shaft and operating at 30,000 r.p.m., the motive power being derived from the cabin blower air at 7 to 9 lb. P.D. (pressure differential) which was over-compressed—cooled—then expanded across the turbine down to 1½ lb. P.D. The limitations of such a system were clearly the limits set by the available energy in the air from the cabin blowers and during engine idling this energy would be negligible. He believed operators in America proposed to overcome this difficulty by accepting a rather high engine idling r.p.m. (1,200 to 1,400) in order to increase the cabin blower output. The drawback here, apart from the increased fuel consumption, was the possibility of engine over-heating. If the refrigerator could be divorced from the blower and an alternative source of power made available many of these difficulties would disappear. Present requirements insisted that the refrigerator must be designed as a removable item of equipment with the object of saving weight when ambient conditions rendered refrigeration unnecessary. So far as Rootes blower installations were concerned these requirements could easily be met, but with centrifugal types fresh problems were introduced in adapting the change speed mechanism to suit the reduced blower load at low altitudes. Taking all things into account he would find it difficult to make a really good case for centrifugals notwithstanding the U.S.A. preference for this type.

The question of using an alternative source of power for refrigeration raised some interesting points of comparisons between vapour compression types and the air cycle type as represented by the compressor/expander. Theory indicated the air cycle to be most inefficient and one wondered whether too much had been sacrificed for the lower weight and bulk of the compressor/expander without giving more thought to the advantages of a vapour compression system for heating—as well as cooling—and thereby make one set of equipment serve a dual purpose. American sources indicated that a typical air cycle system weighed 25 lb./ton refrigerating capacity compared with 65 lb./ton for the vapour compression type, but a recent British design of compressor/expander was likely to improve on this figure of 25 lb. by a good margin and if American weight estimates of

vapour compression types were based upon standard industrial units, it did not seem beyond the capacity of British designers to produce a satisfactory vapour compression refrigerator as regards weight and bulk, yet adaptable for use as a heat pump, using contaminated air from the cabin exit valves as a source of heat. As a long-term project the Philips air engine operating in reverse would also seem to have interesting possibilities for both heating and cooling purposes and when more was known of this project mechanically no doubt this application would be investigated.

To what extent did Mr. Widgery think reheating would be necessary? Alternatively, would it be better to reduce the temperature of a small quantity of air down to, say, 0°F. and reheat by mixing with the remaining cabin blower output? The much-discussed C.E.T. basis of determining refrigeration requirements should be of benefit in any reheating problem, as an increase in dry bulb reading would not necessarily reduce the C.E.T. figure because of the reduction of the relative humidity.

When considering refrigeration for military types of aircraft, he did not think the compressor/expander had any competitor. The comparatively small air flows to be dealt with should enable duct cooling to suffice, thus dispensing with the need for an inter-cooler and such a unit could be made extremely small and compact by high speed operation on the lines of the air-research models. If primary cooling could be achieved by omitting the stationary aircraft condition—not an impossible thought for military aircraft—they might even dispense with the secondary compressor and operate the turbine with the pressure differential available from the primary blowers.

There had been a minor error in the stated capacity of military-type Rootes blowers, which should read 2 lb. not 5 lb. mass flow at 40,000 ft.

MR. WIDGERY'S REPLY

Fortunately, most of the elaborate ducting was run at cabin pressure; it was used only to guide air from one place to another. Therefore, it needed no great strength, and small leaks were not catastrophic. A lot of attention had been paid to ducting, directed especially to reducing its impedance to the flow of air; it was ½ h.p., which was quite reasonable, on a small aircraft. Fairly considerable horse-powers were required to circulate the air.

The evidence available to him was to the effect that somewhere about 43,000 ft. was the limiting height at which people could exist without pressure; even full oxygen was insufficient to support life reliably in the case of unselected passengers, although it would be sufficient in the case of specially selected subjects. At the moment he did not know of any precautions other than that of forcing the pilot and crew to wear masks, or of providing some control which would turn up the oxygen flow automatically to compensate for pressure drop. But for flying higher than 43,000 ft. he had never heard of any pressure control which would protect aircraft passengers from the effects of explosive decompression.

Mr. Saunders had disagreed with him as to the advisability or otherwise of tapping turbines; he had stated that it was such a simple and attractive proposition that it seemed a pity that the concensus of opinion was against it. It did seem a great pity to have to set more machinery to work, with a little pump, when there was a big one available and ready to be used. However, one could only be guided by the engine people.

He agreed entirely with Mr. Saunders that there must be intense development in matters of temperature control and refrigeration, in order to provide the full comfort that was

needed. Indeed, he believed that sufficient attention was now being given to such problems.

He had obtained some very valuable data from the Meteorological Office concerning humidity, temperature, and so forth, and the list was extensive. So that such information did exist.

The larger square on the comfort diagram for Americans was due to the tolerance of the Americans to very high temperatures, or their liking of high temperatures.

When he had stated that the requirements of military and civil machines were converging, he had implied that hitherto on military machines a fair safety margin could be provided for the crews by allowing them to wear oxygen masks, so that cabin failures would not necessarily be disastrous; but that as they progressed, military machines would fly at such heights that oxygen alone would be insufficient to safeguard them. Therefore, it seemed to him that every precaution evolved must be applied equally to military and civil machines. Naturally, such precautions would not protect the crews of military machines from risks of war, such as being shot at, but should protect them from risks due to failure or partial failures of the air conditioning in the aircraft.

Perhaps he had been somewhat too optimistic with regard to air purification. The investigations at the moment were not sufficiently advanced to enable one to state precisely what form the air purification would take.

As to the cost and weight involved in the direct use of fresh air, in an aircraft to carry 30 people the blowers consumed something of the order of 60-70 h.p., which was quite appreciable; that meant an appreciable petrol weight or loss of performance, whichever way one looked at the problem. He would provide more information on the matter for Mr. Scott Hall.

With regard to ground testing, he presumed that Mr. Scott Hall had in mind extensive development tests. It was the policy to do more extensive development tests, to do all that was possible to ensure that everything that went into use was thoroughly tested and proven.

The noise from the blowers was considerable; and at higher altitudes the blowers were working at higher compression ratio, which meant that their noise was even greater. The Rootes-type blower was more noisy than the centrifugal type. But the single-stage blower would become inadequate very shortly for flying higher, and there was every likelihood that multi-stage centrifugal blowers would come into use. The purpose of the duplication of silencers was to prevent pipe resonance.

He was delighted to hear that the Australian operators were asking for pressurisation; he had not known.

It was undoubtedly true that temperature and humidity were closely related; always with a high humidity a lower temperature was required. He was also interested to hear that when the humidity was as low as 3 per cent., one still felt cold. One of his minor ambitions was to study those matters rather more closely; he and his colleagues had done some work on it, but he would like to do more. He had become humidity conscious since he had been engaged in work on pressurisation, and he had a humidity indicator on his desk. During the winter he had noticed that, if the humidity were below 12 or 15 per cent., one was still uncomfortable, whatever one did about it, even if one turned on more heat. That emphasised the need for humidification.

The question concerning the amount of leakage that was permissible from a pressurised cabin was difficult to answer, because, provided that none of the blowers went wrong, the leakage could be equal to the output of the blowers. But he believed it was true to say that the leakage from the British machines now being built was so small that

it was difficult to assess what was a fair allowance; he did not think that was an overstatement of the case. Always in the case of the military machines there had been a requirement that in the event of failure a certain time should elapse before the pressure was halved; he did not think there was a similar requirement for the civil machines.

The popular scheme for preventing door leakage was the provision of something which could be inflated, such as rubber tubing, around the door frame, so that when the door was shut, the tubing could be pumped up so that the door frame was airtight.

He assured Mr. Willis that automatic valves were in process of development and would be available in the near future; their development was well advanced.

He felt he must accept the President's rebuke concerning the nomenclature; perhaps its adoption was due to the reading of a lot of books on the subject.

Written reply:

Referring to the remarks made by Mr. N. E. Rowe, he regretted that the paper might have given the impression that there was need to be shame-faced about providing comfort; on the contrary, he thought that the maximum of comfort was essential. The point he was trying to make was that up to now it could be argued that pressurisation had contributed purely to comfort, while in the near future it would become vital in making feasible economical flight with the new aircraft and power units available.

He agreed that the noise problem remained troublesome, and there was a possibility that it might become more acute with increasing altitude. He was not in a position at present to say what intensity of noise was emitted by multi-stage blowers. The noise of the several stages might or might not be accumulative.

The probabilities were that a practicable and efficient system for filtration and purification might require a long development period. Although it might be found relatively easy to render the air pleasant for the occupants, the problem would be much influenced by the degree of purification considered necessary by the physiologist.

As regards the economic limit in terms of height, he was not in a position to give a useful estimate at present. It might be said however that the weight of equipment necessary should rise but little, so that decisions would be decided rather by the greater economy to be expected from flying at the greater heights.

As regards the impression of complexity he and his organisation were fully alive to the need for simplicity, but they must bear in mind that automatic devices of one sort or another were employed to ease the burden on the flight crew. They saw everywhere the same trend towards simplicity of operation by the development of automatic devices. The chief defence against maintenance problems appeared to lie in the exercise of judgment to avoid the inclusion of very delicate or vulnerable mechanisms concurrently with a programme of development so that weaknesses could be discovered at an early date. The course was pursued and prolonged endurance tests under representative conditions were now a part of their development programme. The problem of reproducing actual operating conditions was considerable, but their test conditions covered operation at low temperatures, etc.; all the flight trails to date did in fact confirm that a high degree of reliability had already been achieved.

He considered the question of preventing icing of the safety valves to be of the greatest importance, more especially when humidification was employed. Careful positioning was of the utmost importance so that these vital components might be kept warm by the continuous discharge from the automatic discharge valve. The provision of heat by electrical heaters had received attention, but the risk of over-complication to which Mr. Rowe had already referred made such additions undesirable unless they were vital. He

had received no evidence that ice had accumulated either at, or near, the discharge points, although at one time there was some fear that ice might accumulate during long flights.

He had read Mr. Pye's written contribution with the greatest interest, but the issues raised were so fundamental and far-reaching that he felt it would be impossible to deal adequately with them in this discussion. He was indebted to Mr. Pye for a most valuable contribution.

THE ROYAL AERONAUTICAL SOCIETY

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MAINTENANCE DIFFICULTIES IN THE FIELD

by

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1. INTRODUCTION

The recent war has provided a great deal of experience in the operation of aircraft and ground equipment under a variety of conditions. This paper is an attempt to condense and correlate some of the points noted into a logical sequence. It is not based on statistics and is more in the nature of a selection of problems and impressions about them. Possibly this is an advantage, as it seems doubtful if many logical conclusions could be drawn from a set of completely comprehensive observations, even if these were available.

2. COMPARISON OF SERVICE AND CIVILIAN MAINTENANCE

Before any attempt is made to apply Service experience to civilian operation the differences between Service and civilian maintenance must be studied.

The main differences are:—

(*a*) Lack of spares and equipment during the war.

(*b*) Lack of skill of maintenance men and, in some cases, lack of specialised training.

(*c*) The variety of types in use.

(*d*) Operating conditions in the air and on the ground.

(*e*) The urgency of maintenance for operations.

(*f*) Rapid modification necessary to meet operational requirements.

(*a*) Lack of spares and equipment during the war was, almost always, a major difficulty which had an adverse effect on the life and maintenance of aircraft. A notable example of this was the re-grinding of used piston rings for Bristol aero-engines as was done in East Africa, which greatly reduced the effective overhaul life of the engine. Apart from a general lack of spares of all kinds, there was also a considerable lack of special tools and major equipment, such as slipways, hangars, suitable storage for parts and fuel, and so on. These factors made first-rate maintenance difficult and sometimes impossible, and also magnified the difficulties arising. There was also a considerable wastage of time and manpower because of the necessity for removing serviceable parts from one aircraft to service another. Cannibalisation, often of a new aircraft, was frequently the only method of maintaining reasonable serviceability.

(*b*) The lack of skill of maintenance men during the war was unfortunate but inevitable. From the point of view of a study of maintenance this may have been an advantage since most of the mistakes made are liable to occur in any case and cannot be ignored.

(*c*) Most Service units suffered from the large variety of types in use at one time and also from the large variations between aircraft of the same basic type. This state of affairs enhanced the already great difficulties

experienced because of the lack of spares, tools and equipment, and it meant that maintenance crews were often called upon to work first on one type of aircraft and then on another. Difficulties under this head are not likely to be so great in civilian operation.

(*d*) Operating conditions were usually much more severe than would be tolerated in civilian operation. There was a constant tendency to overloading. Aerodromes were often inferior and frequently inadequate. Dispersal deprived aircraft of protection from the weather and increased the amount of taxying necessary. Aircraft were flown under much worse weather conditions than those accepted for civilian flying and there was more night flying. Aircraft had to be maintained under arduous climatic conditions at places where civilian aircraft might be expected to make only a short stop.

(*e*) Because of the urgency of maintenance and servicing much attention had to be devoted to the organisation of every stage of maintenance; while some of the ideas developed, such as planned flying and planned maintenance, are of little practical value in civilian operation, many of the difficulties arising are of equal interest, *i.e.* the rapid refuelling of large aircraft.

(*f*) Rapid modification of civilian aircraft does not occur on anything like the same scale as with Service aircraft. There are always more Service aircraft to do, they are spread around more and the urgency of flying the aircraft as soon as possible is often much greater.

While some of the difficulties found in the Service are irrelevant to civilian operation, the remainder are only an aggravated form of similar difficulties which arise in normal use and are worthy of study.

3. INSPECTION

In his paper "Development of Air Transport During the War" (JOURNAL of the Royal Aeronautical Society, April 1947), Air Marshal Sir Ralph Cochrane pointed out that the minimum desirable overhaul life for aero-engines is 1,000 hours. The parallel to this for airframes is a 500-hour major inspection cycle with minor inspections every 100 hours. These requirements are an immediate target and should be achieved rapidly in civilian operation. Pratt and Whitney Twin Wasp engines were operated in flying boats in the tropics, under extremely arduous conditions and were found to give perfect satisfaction on an 800-hour overhaul life. Several aircraft are operating about 80-hour minor periods with major inspection periods of about 400 hours.

The importance of an adequate time between inspections cannot be over-stressed. An extra 10 per cent. on the minor inspection life appears to make a considerable difference to the total flying time that any one aircraft can complete in a year. Unfortunately, no figures are available for this. In some cases minor inspection periods were made to fit the time taken on a particular run. This is obviously the ideal and consideration should be given to widening the time limits at which inspections should take place in order to fit them into the turn-round of a particular route.

All those who have operated aircraft will appreciate how often aircraft coming off minor inspection produce a string of delaying and annoying snags. Neglecting such things as settings which are affected by adjustments and so on, it would appear that there ought to be a different approach to the type of work which should be done on minor inspections.

The most important thing is a thorough cleaning down of the aircraft, particularly the engine nacelles. Many defects were found to be caused or partly caused by the accumulation of dirt, grit and mud. Such defects included the faulty operation of undercarriages and warning devices. In addition, an inspection cannot be done quickly or efficiently unless the parts are clean. Grit can also be a source of wear and scoring.

Special equipment is required for this cleaning to be done quickly and pressure steam jets appear to be used in America for this purpose.

Once the aircraft is thoroughly clean the bulk of the work done on minor inspections should resolve down largely to servicing, *i.e.* changing plugs, checking points and pressures, topping-up systems, retraction tests, harmonising guns and so on. All other items should be examined with a view to down-grading them to major inspections. All components should be capable of maintaining the same life as the engine or airframe, without attention other than greasing and so on. Certain checks of vital systems such as controls must, of course, be maintained. Also, certain items are liable to loose adjustment with use and require checking. Numerous checks for security should be rendered unnecessary by suitable fixing and locking. Generally speaking, all such checks could be done on the first minor inspection after the major inspection. This would allow time for all such items to "shake down." It is difficult to be dogmatic on this point but the suggestion is that more attention should be concentrated on the first minor inspection after the major at the expense of the other minor inspections, which would be more of a servicing nature.

4. INTERCHANGEABILITY

(*a*) Broadly speaking, the major components made for aircraft during the war were seldom interchangeable when the aircraft were not new. This also applied to American aircraft. It might be worth while making an investigation into the possible changes in dimensions of an aircraft during service. It is obvious that unnecessary time taken in changing components must be avoided, but it is not always so obvious that extra losses may occur if the time taken over such changes cannot be estimated reasonably accurately, say to the nearest half day. Thus, a replacement aircraft may be arranged when it is not really necessary and *vice versa*. In addition, it is often impossible to forecast when delays will arise, even with apparently simple changes. For example, in the case of a Dakota door change, where the only important points were two hinges, two locks and a reasonable fit with the other door, it was found that the doors of aircraft in use varied widely and that a change which might have been expected to take less than one hour took more than a day. In such a case variations might be caused by use or misuse in service, as well as initial variation of dimensions and possibly the loading condition of the aircraft at the time of the change.

It is suggested that the attachments of components likely to be changed should be few in number and accurately jigged and rigid. Rivet holes should, as far as possible, be drilled in position. This procedure might involve a slightly higher structure weight but would go a long way to prevent distortion and pre-stressing. The type of construction in which joints are made at flanges by means of a large number of bolts, is undesirable from the point of view of rapid changing and interchangeability. Also, where use has to be made of manholes to obtain access to the bolts, it may be found in the tropics that work can only be done at night, or in the early hours of the morning.

(*b*) Interchangeability of cowlings is important, as they are removed frequently and any time saved would be invaluable. Also, it is undoubtedly true that some buttons are left insecure and serious accidents have occurred because of cowlings being carried away in flight. Badly fitting cowlings must have an appreciable effect on the performance of the aircraft. There is no all-embracing cure but some suggestions are offered. Cowlings should not be too large as a single piece; they should be made from heavy gauge sheet and be adequately stiffened; and buttons should be placed on sheet thick enough to prevent distortion. Many of the

troubles found in fitting are caused by the buttons ceasing to be perpendicular to the surface which, in turn, is caused by local bending of the sheet on which the buttons are mounted. As far as possible cowlings should be hinged so that they do not have to be completely removed to provide access. This would prevent damage on the ground and minimise loss. Undoubtedly, wire-bound cowlings are, where practicable, the best solution. Wooden, or wood and fabric, covers and fairings often provide difficulties in re-fitting because of shrinkage and warping.

(*c*) A special note is added here on the question of the interchangeability of magnetos and harnesses. During the war it was thought wise to have three makes of magneto for many types of engine. The idea was that, in the event of a certain works being destroyed, production could continue. Unfortunately, the magnetos were permitted to be physically different and there were also considerable differences in the ignition harnesses. The result was that units had to carry spares for three types of magnetos and harnesses and it was usually found that the type required was unavailable. The Americans also did the same sort of thing but with much less justification. It is realised that this sort of thing is decided at a high level and it is to be hoped that operators will insist on interchangeability in such cases.

5. ACCESSIBILITY

Accessibility is most important because it vitally affects the time required for maintenance and inaccessible items are seldom maintained properly. It must be remembered that the maintenance man operates under special difficulties which neither the designer nor the production engineer may appreciate fully. He has to work on the complete aircraft and cannot choose the most suitable stage in assembly for a particular job. For example, in his paper "Production Problems in Relation to Aircraft Design" (JOURNAL of the Royal Aeronautical Society, June 1947), Mr. Fielding pointed out that, on the Lancaster, items on the forward side of the bulkhead bearing the instrument panel were fitted before the nose was in position. No doubt this was essential from a production point of view, but the maintenance man might have to change any, or all, of these items with the nose in place. If such short cuts are accepted too readily during production it may result in components being physically impossible to change. It also seems likely that insufficient attention will be paid to easing replacement difficulties. The particular problem involved, that of pilot's instruments and controls, is most important because, almost invariably, these items are cramped together in a small, confined space and they require frequent attention. In the case of the Dakota the problem is dealt with by permitting the upper half of the nose cowling to hinge upwards. This appears to be suitable for many civilian types and it might be an advantage, in other cases, to provide an access door in the floor or side.

Another suggestion is that the instrument panel, or parts of it, should be able to hinge forward for access. In any case this problem justifies more attention than it appears to receive. A re-allocation of the positions of items from a maintenance point of view might be possible, for example, engine controls on the roof, as in the case of the Catalina, and complete transference of many gauges to the engineer's position.

Engine accessibility is often poor. Such items as carburettors, fuel pumps, hydraulic pumps, compressors, generators, starters and so on, frequently have to be changed, and for some starters it is necessary to sling the engine out of the bearers to effect the change. The clutter behind the engine is often appalling. It is suggested that, for all types of piston engine, the magnetos should be placed on the front cover. This makes the magnetos and harness much more accessible. Fresh consideration should be given to the use of

auxiliary gear boxes, as the use of the gear box must make the components more accessible.

There is little doubt that accessibility is a point on which the maintenance side should be called in at the design stage. Above all, it must be remembered that the maintenance man operates under special difficulties such as exposure to the weather, lack of some pieces of special equipment and rigs and, in some cases, lack of specialised knowledge.

Attention has also been drawn in the correspondence columns of the JOURNAL of the Royal Aeronautical Society to the need for fully-decked aircraft to minimise the number of small items which drop out of sight, and often out of mind, in the bottoms of fuselages and also, to present a surface which can be cleaned readily. Many jobs centre around the crew positions and a good decking at these points would be well worth while.

6. STANDARDISATION

(*a*) There is a great need for a higher degree of standardisation of aircraft parts such as: pipes and connections; instruments, together with their attachments to airframe and engine; tank filling orifices; all types of cocks and valves; all types of filters and cleaners; ignition harnesses, plugs and connectors and other electrical items.

Much has been said recently of the variations found in items fitted to different types of British motor cars. It has been said that the types of accumulator supplied by one manufacturer alone run well into double figures, while four would probably serve all normal purposes. However objectionable this may be, the parallel for aircraft parts is much worse. The motor industry has been able to turn out large numbers of each type produced and this has tended to conceal the extra cost and waste inherent in lack of standardisation.

For aircraft the position is different. The number produced of any one type is considerably smaller, while the number of components for which non-standardisation is possible is vastly greater. The items themselves are usually intrinsically much more expensive than motor car parts and require much more attention in storage. Also, it is often impossible to go to the next aerodrome "down the road," as might easily be done with garages.

It is difficult to exaggerate the waste of time, money and space involved in stocking, ordering, awaiting and storing the complexity of accessories and parts which are in use at present, but the most irritating factor is that often much of this extra work is largely pointless. Mention has already been made of magnetos and harnesses but the remarks made apply to a wide range of parts. For instance, it is possible to go to a rack holding 12 different types of compressor and find that the one required is missing. The same applies to generators, starters, hydraulic pumps, fuel pumps and many other accessories.

It is right and proper that manufacturers should at all times attempt to improve and modify their products in the light of experience, but the value of the improvement to the operator should always be considered alongside the complication in service before new parts are fitted. Manufacturers should attempt to maintain at all times as high a degree of standardisation as possible throughout the marks of aircraft of one type. In addition, there should be a higher degree of standardisation among different manufacturers. Standardisation should be one of the primary criteria in the consideration given to accessories in the design stage. The standardisation of components could be of the utmost value in enabling air lines to pay their way.

(*b*) It is suggested that hydraulic fluids should be standardised because there is always a chance that an aircraft will be filled with the wrong type of fluid at some time in its life. Indeed, a close examination of a

hydraulic system will sometimes show signs of this. It seems doubtful if any improvement in the performance of a hydraulic system, achieved by the use of a special fluid, is likely to counterbalance the possibility of total loss which might arise from the mixing of fluids in service.

(*c*) Locking devices are a field in which standardisation could be used to great effect. It should be possible to determine the type which is the simplest, most efficient, easiest to use in inaccessible places and generally best in service. Anyone who has tried to split-pin a set of nuts in an inaccessible position will realise just how much time could be saved by use of the optimum locking device.

There is a requirement in some cases that the locking device used should permit tightness checks to be made by a torque spanner with a minimum of disturbance. Again, locking devices which can only be used once, with safety, are undesirable as there is always a tendency to re-use, even when a plentiful supply of new parts is available.

7. SPECIALISED TOOLS

Correspondents in the JOURNAL of the Royal Aeronautical Society have mentioned the undesirability of special tools. These tools represent extra cost. Either extra tools must be provided at a number of places, or aircraft must be held on the ground awaiting tools. In either case the result is extra cost. In addition, the tools themselves are expensive, they are restricted in their usefulness and they cause extra storage problems. Also, it is too frequently the case that special tools become special to a particular mark of a particular aircraft, resulting in different types of a similar tool being required. There is some difficulty in identifying the correct and complete kit of tools required to do a particular job. This is important when the question of the holding of tools at different staging posts is raised.

It is only necessary to think of propeller tools to realise that it is impossible to do away with special tools, but much can be done. The germ of the idea lies in the preceding note on inspection periods. If all components can be held to strictly servicing attention only, over the whole major inspection period, it should be possible to get by with few special tools. Discounting the irregular defects, the large-scale regular jobs during the running life of many aircraft cause most of the trouble. For instance, the exhaust system of a well-known fighter was found to burn out after about 240 hours running. The resulting job then occupies two men for some seven days and during this time they have to use a number of special tools. A similar example is the changing of cylinder blocks on certain engines when they first came into service. If a component cannot hold to its major inspection time without regular major work being done on it, that component should be withdrawn.

The old system of boxing tools as kits in special wooden boxes should be reverted to, so that empty spaces immediately reveal missing tools. In addition, adequate information should be available as to the tools required to do each job and this information should be kept up to date in such a way as to retain the requirements of back marks. Some standardisation of special tools might be achieved. For example, if sparking plugs and connectors were standardised it might be possible to produce a standardised plug spanner. During the war the rate of progress on minor inspections was often dictated by the number of serviceable plug spanners available.

As far as possible, designers should sight components so that special tools may be avoided. If a special tool is accepted it should remain unchanged on future marks of aircraft, if this is at all possible. In the case of tools which are likely to be in constant use during servicing, an extra effort should be made to avoid the use of special tools. When

special tools are made they should be carefully designed and well made. If they break, the maintenance man is often left in a difficult position, as there may not be another tool and the location may be such that he has to start and make a similar tool before he can proceed.

8. POWER PLANTS

Unfortunately, despite many efforts, the author has no personal experience of an actual complete power plant change. In order not to bypass this important subject altogether a few of the difficulties involved are noted. Many of these difficulties are peculiar to operational units and squadrons based anything up to 5,000 miles from their sources of supply. For this reason none of the remarks made are intended to deny the practicability or desirability of the use of power plants for civilian operation, but it is felt that these difficulties should be mentioned.

The most important point is that, with multi-engined aircraft, the power plants for all engine positions should be identical as far as possible. This is difficult to arrange from an accessory point of view and might even be impossible, unless certain accessories are driven separately. If two or four different power plants are used on one type of aircraft, a large increase in the holdings of spares at points along the route becomes necessary. At one unit four Lancasters were held on charge, each with a different mark of engine from the others and there were other important differences in propellers, governors and so on. This merely indicates the complication that can arise.

Power plants are bulkier and appreciably heavier than bare engines and it will not be as easy to move them by air, although the position can be eased by using specially designed transport stands. Thus, if the advantages inherent in the use of power plants are to be properly utilised, adequate stocks of all types for possibly six months' consumption might be necessary at all distant airports. On balance, it might be best to adopt a single power plant for each aircraft and to supply certain accessories loosely so that the power plant can be finally made up before use as required. This will mean that power plant changes in say, less than an hour, are unlikely but the saving in stocks of plants will be considerable. It is obvious that consideration must be given to the question of power plants at a fairly early stage in design and that the representatives of the maintenance side should be consulted. No doubt some of the complaints made against power plants are caused by attempts to superimpose them on an existing design.

As pointed out earlier, spares shortages often affected R.A.F. maintenance severely and this was particularly true in the case of power plants. A new power plant is the ideal thing for cannibalisation and it is difficult to prevent this when an operational squadron commander is really short of aircraft—whatever the written instructions may say. Also, as was only right and proper, operational units had priority call on spares over the Maintenance Units trying to build power plants. The Maintenance Units could never combat the three-line whip of an operational commander's aircraft on ground demand for spares. Whatever the niceties of the case, all right-thinking engineers will agree that it is better to keep an aircraft flying on operations than to keep a power plant standing idle. Not only did the operational units have first priority on spares but they also had a probable first pick at unserviceable power plants before they were returned for overhaul. Thus the operational units had two holds over the Maintenance Units and the latter had the greatest difficulty in supplying complete power plants when spares were at all short. Moreover, there is no half-way house in power plants. If units cannot expect a complete power plant they will rob the unserviceable one unmercifully. The matter was further complicated because, on some

aircraft, parts of the cowling rings were found to wear considerably, thus necessitating a high degree of replacement. This comment is offered in reference to some light alloy parts on certain American aircraft.

Shipping space was of the utmost importance during the war. As an example, Pratt and Whitney Twin Wasp engine cases were carefully designed to the minimum external dimensions, no outside battens were permitted and flush eyes were fitted for lifting the case tops. It is obvious that power plants will require much more shipping space than bare engines. The extra difficulty of air movement has been noted. In addition the crated power plants are heavier and will take up more storage space—a very important point when covered storage space is at a premium.

Where these difficulties arise in civilian operations, they should be regarded as difficulties to be overcome because rapid engine changes can bring a great saving in money and well-designed power plants appear to be the best way of achieving them.

9. GROUND EQUIPMENT AND GROUND HANDLING

It has been pointed out that the most important considerations in the design of jacks and other lifting devices appear to be that they should be as heavy as possible and mounted on the smallest wheels possible. The combination usually means that at least one hour is occupied in jacking up an aircraft before a simple process, such as a wheel change, can be started. Moreover, when aircraft are undergoing maintenance in the hangars, time spent in jacking almost always restricts the work of all other personnel employed. Jacks should be made as light and manœuvrable as possible, and as much assistance as possible should be given to the user, such as some form of incorporated aligning device and an overload gauge, possibly operated by hydraulic pressure.

Not all the faults occurring in jacking are caused by the jacks themselves. The positioning of jacking points on the aircraft is important. For instance, on the Liberator the main jacking points are immediately behind the main wheels. Thus, if a main wheel becomes bogged the maintenance man is faced with the problem of setting up his main jacks on broken or soft ground. In addition the attachment points for the jacking pads should be readily accessible. The use of small jacking fittings which can be applied to individual undercarriage legs to permit rapid wheel changes is very helpful.

The question of clearing a runway rapidly after a crash is important and considerable advances were made during the war, but the methods in use could be improved. In some cases it is difficult to avoid doing further damage and extra difficulties arise when the aircraft is badly down on one wing.

In general, refuelling is a primitive process. Under present methods it is inadvisable to refuel in rain and sand and dust can be even worse. Flows obtainable cause undue delay with big aircraft, especially when the tanks are some height from the ground. The use of chamois leathers for filtration causes slower refuelling and the leathers perish rapidly in hot climates. Above all, there is a great fire risk. It is suggested that screw connections are necessary to provide a shielded filling circuit, to give good bonding and prevent spilling. Spilling of both oil and petrol causes deterioration of self-sealing tank coverings and fabric, while oiled surfaces in the mainplanes accumulate dust and grit, causing other troubles. Better methods of filtration are required. Difficulties arise because of the large amount of condensation occurring in the tropics and because of deposits of rust and other compounds in barrels and tins. A centrifugal separator might be used with advantage. It is suggested that spark ignition pumping engines are unsuitable, particularly in the case of marine

refuellers where vapour concentrations can occur in the engine room.

Insufficient equipment is available for sweeping runways in order to minimise tyre damage. In addition to runways, taxiways, dispersals and the entrances to hangars should all be power swept. Cases have occurred of new tyres being ruined before the aircraft had moved 20 yards out of the hangar.

Many items of ground equipment were left by the R.A.F. for local manufacture and this process was never very satisfactory. These items included tyre covers, intake covers, spark plug and other blanks but they should be made an aircraft requirement and their supply should be plentiful. Obviously it is a false economy to use inefficient sparking plug blanks.

10. PACKING AND ANTI-CORROSIVE MEASURES

The packing of British aircraft spares is inferior to American practice. Aircraft spares often complete one stage of their transport by air, so packing must be as light and as compact as possible. Generally, specially designed pressed cardboard boxes to take individual, or pairs of, bulky items are the best solution. An example is the packing of Twin Wasp cylinders. This is much superior to the British method of wooden boxes and felt. Only heavy items such as crankshafts should be packed in wood. The use of cardboard boxes must involve specialised design and testing, it being remembered that nearly always the cost of the part will outweigh considerably the cost of proper packing. It is pitiful to see big end bushes arriving in flimsy cardboard boxes in which one might hesitate to pack cigarettes.

Corrosion and deterioration along the route and in storage is a parallel problem. Great trouble arose at tropical units because of internal corrosion of engines. Corrosion attacked crankshafts, connecting rods, cylinders and other parts to an almost unbelievable extent. Large numbers of new engines had to be stripped for this reason when they were received. R.A.F. inhibitors tended to drain in hot climates, whereas American inhibitors tended to clog internal oilways and cause seizure. Again, numbers of new engines had to be stripped on this account.

The American process of packing in plastic sheaths with moisture indicators is a step in the right direction, but the capacity of the water-absorbing materials was inadequate and most engines arrived with their indicators in the danger condition. Nevertheless, on arrival, these engines were in a good condition internally. It seems probable that the newer American method of cocooning in sprayed plastic may be more satisfactory. In any case, these are points which should receive much more attention.

Ball bearings packed in greased paper travel badly in the tropics and tend to corrode. Rubber and rubberised items seem to deteriorate rapidly and it is not unusual for 60 per cent. of a consignment to be scrapped on receipt.

Losses in transit also make the provisioning of spares difficult. In general, insufficient attention is paid to seeing that spares reach the operator in a satisfactory condition.

11. LOCAL OPERATING CONDITIONS

A great deal more should be learned about local operating conditions. More flying should be done in hot, dry, and hot, wet climates and this flying should be done as early as possible in the life of a new type of aircraft. Also, more attention should be paid to high altitude areodromes. For example, Blenheims operating from Nanyuki aerodrome, Kenya, at 6,500 ft. above sea level were found to suffer from tyre failures. The defect was traced to overheating of the wheel hubs caused by the combination of a higher speed at touch down, because of the altitude, and the high day temperatures.

There is also the old problem of shrinkage of wooden aircraft in hot and dry climates. A

thermometer placed in the mainplane of an Anson at Habbaniya, Iraq, registered a temperature of 160°F. during the early afternoon. Considerable trouble was encountered by the Royal Iraqui Air Force because of the shrinkage of Ansons supplied to them. In many cases shrinkage can be taken up by tightening bolts, but in other cases damage occurs in the form of split blocks, broken riblets and opened joints, although, in aircraft personally inspected, glued joints have usually been found sounder than some structure details. There are also problems in the deterioration of fabric and the corrosion of metal parts in hot and wet climates, such as the Persian Gulf.

These points are additional to all the problems of tropicalisation of aircraft and the resulting reduction in performance and such problems as the overheating of engines during taxying. A further set of problems applies to conditions of extreme cold.

12. MISCELLANEOUS

(*a*) The weather-proofing of aircraft is often unsatisfactory. The worst points are usually perspex window frames, particularly movable ones. This point can be of considerable importance. The case is quoted of three aircraft sent to a dispersed base from which they were to make anti-submarine patrols. On the way to the base they flew through a tropical rain storm. On arrival it was found that the radar equipment of all three aircraft had been made unserviceable by the ingress of water and as weather conditions did not permit a visual search, all three aircraft had to return to their home base. Bad weather-proofing is a discomfort to members of the crew, particularly the navigator, who may have some difficulty in keeping his charts and logs dry. Such conditions are not conducive to efficient work by this most important member of the crew.

(*b*) Without offering any comments it should be pointed out that during the war radar unserviceability was higher than it should have been, so much so that R.A.F. engineer officers would not account for it on their serviceability records. Fortunately, apart from such troubles as damage to external aerials, radar unserviceability can often be overcome in a few minutes by merely disconnecting one set and installing a replacement. Frequently spare sets were carried by aircraft so that such changes could be made in the air, if necessary. Although radar equipment is still in a state of intensive development, far better serviceability is required before it can be as reliable and trustworthy as it should be.

(*c*) Again without offering any comments, instrument reliability was not as good as it should have been. If pilots and flight engineers are to accept the readings of instruments at their face value, these instruments should not be suspect because of flickerings and so on. Many R.A.F. pilots would not rely implicitly on the readings of fuel contents gauges, preferring to subtract their estimate of the fuel consumption from the take-off contents. Such methods can have an appreciable effect on the range of the aircraft.

(*d*) Some form of vibration indicator fitted to engines would be a help to the flight engineer in detecting incipient engine trouble. With multi-cylinder engines, particularly radials, it is surprising how important defects pass unnoticed during normal checks and running. It is possible to miss a broken rocker bracket, or a tappet slacked right off, or a cylinder with two oiled-up plugs. Many pilots and ground crews do not watch the revolution counters when doing single ignition checks. They prefer, from experience, to watch the engine cowling for vibration and in many cases they will locate defects that would otherwise pass unnoticed.

13. CONCLUSIONS

There seems to be an opinion, shown in the correspondence columns of the JOURNAL of the Royal Aeronautical Society, that the

solution to a large number of maintenance problems lies in increasing the skill and knowledge not only of maintenance personnel, but of all those who come into contact with aircraft. Although there is much truth in this opinion it is not the whole answer. It is not enough that a machine should work, it must also be sufficiently robust and able to stand up to fair and reasonable use. This implies a reasonably accurate knowledge of all the conditions in which the aircraft is likely to serve, of all the jobs that the maintenance engineer is likely to have to do and the difficulties which he may have to face. It is difficult to see how this can be obtained without taking representatives of the maintenance and operational sides into consultation at a fairly early stage in the design of an aircraft.

The question of weight is a point which must arise whenever greater robustness is required. Some designers have proved to their own satisfaction that 1 lb. of weight saved is worth £1 to the operator. Undoubtedly, weight is always of the utmost importance but there is another aspect to be considered. It might be possible, in certain circumstances, for 1 oz. of extra weight to be worth, say, £100,000 to the operator. Certainly if, as is the contention of this paper, greater attention paid to maintenance difficulties permits a reduction in the time spent on the ground, the benefit to the operator should be far greater than the loss caused by the added weight. The importance of this point is likely to increase since, as aircraft become larger, the number of parts and consequently the number of possible defects, will also increase.

One point on which the co-operation of design, maintenance and operation staffs should be exerted to the full is the question of accident prevention. Three recent and much publicised flying accidents involved such things as crossed flying controls, external control locks not removed prior to take-off and hoar frost left on the mainplane. All these things have occurred often enough in the past and the real tragedy is that steps have not been taken to deal effectively with them, or at least with the first two. Crossed flying controls, for instance, should have been designed out of all the aircraft built for the past thirty years. A great many aircraft accidents, and incidents which through good luck or judgment never become accidents, are due to comparatively simple things which are only too painfully obvious, rather than to abstruse mechanical and aerodynamical troubles. Much could be done to minimise the probability of human errors resulting in accident to the aircraft.

It is realised that, as with many other things, too many "cooks" may well spoil the design of an aircraft. It is also realised that many outside influences have acted to confine the best endeavours of the design staffs —such things as availability, time factors, higher policy and so on. But, it is thought that operating and maintenance problems, as far as they can be ascertained in the light of past knowledge, should be ably presented at an early stage in the design of an aircraft so that all the technical skill and knowledge available to the modern designer may be utilised in their solution. Only in this way will flying become safe, reliable and cheap.

CORRESPONDENCE

18*th September* 1947.

With reference to the paper "The Behaviour of Structures under Repeated Loads" by Professor Pugsley in the September 1947 JOURNAL, may I make the following observations:

The determination and use of test results to construct the type of diagram described by Professor Pugsley are complicated by two factors: (i) the problem of defining precisely "static strength" for the purpose of applying the test loads; and (ii) the possibility that the test values may embody a combination of the effects of variation in static shear strength and of the repeated or reversed loads.

Thus, it might be required to investigate the effects upon a certain form of aluminium alloy bar of repeated tensile loads varying from zero to 50 per cent., 75 per cent. and 90 per cent., say, of its "static tensile strength," given reasonably reliable information from static tensile tests on a number of specimens. Such information could comprise the mean, standard deviation and a good fit to the normal theoretical frequency curve embodying these parameters. For the purpose of the repeat load tests it will be necessary to select a suitable value for "static strength," of which the specified percentage loads are to be applied. If the mean is adopted for this purpose it is evident that the specimens are quite likely to break under the load imposed upon them in the repeat load test rig before any repeats have been applied, particularly under the high percentage values. A more rational value of static strength would be the "safe" value or that value below which the specimens are unlikely to fail statically, *e.g.* the mean minus $2 \times$ standard deviation. It will now be fairly safe to assume that failure of the specimens during the application of the repeat loads will be due to the effects of the latter only. The test results will consist of a set of numbers of repeats at which the specimens have failed, but as such they are probably misleading in so far as concerns the effects of repetition of load, for the reason stated in (ii) above. It will be necessary, therefore, to separate the combined effects of static strength variation and repetition of load. This could be done by treating the set of numbers of repeats as a frequency surface, one axis of which refers to the known static strength variation and the other to the as yet unknown scale of repeats, due regard being paid to the correlation coefficient. On this basis the effects of load repetition can be isolated and a frequency distribution obtained for the numbers of repeats alone. From such a frequency distribution the mean and standard deviation can be derived and, if the distribution is approximately normal, used to estimate the "safe" value of the number of repeats below which the type of specimen being investigated is unlikely to fail. For the purpose of constructing the modified Goodman diagram the "safe" values of repeats and of static strength would be plotted.

Investigations on the lines outlined above would require a fairly large number of specimens to be tested for satisfactory results and consequently the work and expense would become prohibitive, no doubt, for large and complicated structural components. On the other hand, in face of the increasing interest being shown in the effects of repeated and reversed loads and of the scanty data at present available it may be that work on simple structures such as riveted, or welded, joints or on materials, would repay consideration and might even serve as a basis for information concerning such major structural components as aeroplane wings, and so on.

B. Saravanos, Associate Fellow.

REVIEWS

The ABC International Airways and Shipping Guide. T. Skinner & Co., London. 3/- monthly.

The foundations of history are not always as clearly seen by those who live in history as the sky-scraper erections which are so obvious and so ugly.

Future air historians, delving deep in the foundations of the past, will seize eagerly upon publications such as the one under review, for here is the very essence of history. They will learn, in consecutive paragraphs, that to fly from London to Ramsgate, the air traveller must make his own terms with an air charter company, but to Rangoon he can buy a return ticket lasting for a whole twelve months (although to Paris he will only be allowed two months!). They will also learn that for any aeroplane over 6,000 lb. in weight it was cheaper in 1947, in Great Britain, to land on grass than on concrete.

The reviewer learned that it does not matter what state of health he is in if he wishes to fly to any European country, but he must be fit to fly to Canada.

One could go on quoting from the historical point of view, but the real present value of the ABC is as a guide to the air services of the world, and in that it is excellent, giving just that kind of information the air traveller wants.

After he has obtained it, he is in the hands of the air transport companies—but the remainder of the alphabet would be required to review their activities, or lack of them, for they are not as simple as ABC.

Modern Gas Turbines. A. W. Judge. Chapman & Hall, 1947. 28s. 0d. net.

To the growing list of books on engines of all shapes, sizes and kinds, Mr. Judge has now added his latest "with special reference to stationary, aircraft, locomotive, and marine types and to the supercharging of internal combustion engines." They form a most excellent and useful series.

This book covers a wide field, from the early history and development to materials for gas turbines and it is significant that the longest chapter is that dealing with Gas Turbines for Aircraft. It is not an unlikely forecast that this chapter will expand into book form. Although early gas turbine development was so largely due to industrial demand, there is little doubt that the intensive development due to aeronautical considerations will lead to greater improvements in industrial gas turbines. Without being too self-opinionated the Aircraft Industry has now approached the stage where it is giving more to other engineering industries, in the way of technical progress, than it is receiving, whether it be structurally or on the engine side.

The author has drawn upon a large number of sources for his information and his bibliography on pages 299-303 is most useful. The publishers, despite the severe handicaps of labour, paper and other shortages, have contrived to keep up the high standard which is characteristic of their technical publications.

Introduction to Aerodynamics of a Compressible Fluid. Hans W. Liepmann and Allen E. Puckett. John Wiley and Sons. 1947. 4 dollars. 262 pages.

This book is a really valuable contribution to aerodynamics. It is the first book of its kind to deal with the aerodynamics of a compressible fluid, providing in concise and

simple form the background of theoretical and practical knowledge necessary for investigating the transonic and supersonic regions.

The first part of the book includes a thorough discussion of one-dimensional gas dynamics and its application to supersonic wind tunnel design; the second part is devoted to the more general two- or three-dimensional equations of compressible flow and the existing methods of solving them.

The book is well produced, most attractively written and should prove of great value to students, aeronautical engineers and scientists.

Elementary Applied Aerodynamics. Paul E. Hemke. Constable and Company. 1947. 26/-. 224 pages.

This book is part of the Prentice-Hall Aeronautical Engineering Series and, as stated in the preface, it is intended to meet the requirements of a first course in applied aerodynamics. The preface also states that the material covered is not unusual, which is perfectly true. What is unusual is the material which is omitted. For instance, there is no information on wind tunnels, on stability, or on control surfaces. The small section on flaps gives data on plain and split flaps only and nothing on leading edge slots; among several chapters on the physical properties of air and air flow, there is no mention of the pitot tube. Examples are included at the end of each chapter, and the book is freely illustrated with diagrams. It is unfortunate that in some of these diagrams the large size of the printing detracts from an appreciation of the curves. Otherwise the book is well produced.

It is not considered that this book makes any significant contribution to the study of elementary applied aerodynamics, a subject which has already been covered by numerous books of better value.

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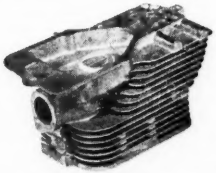

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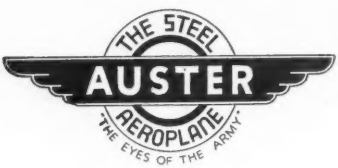

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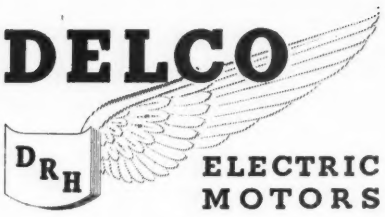

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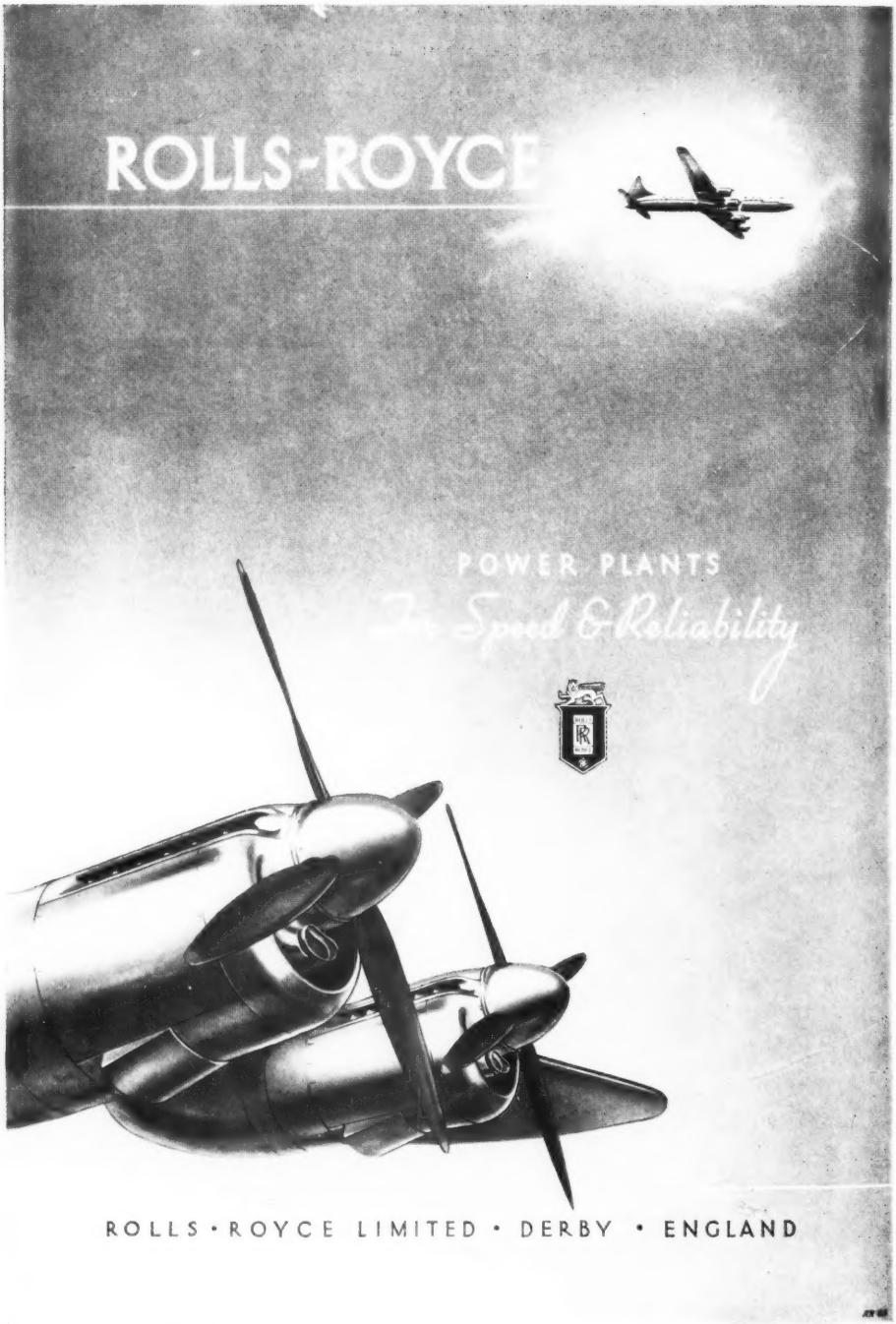

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